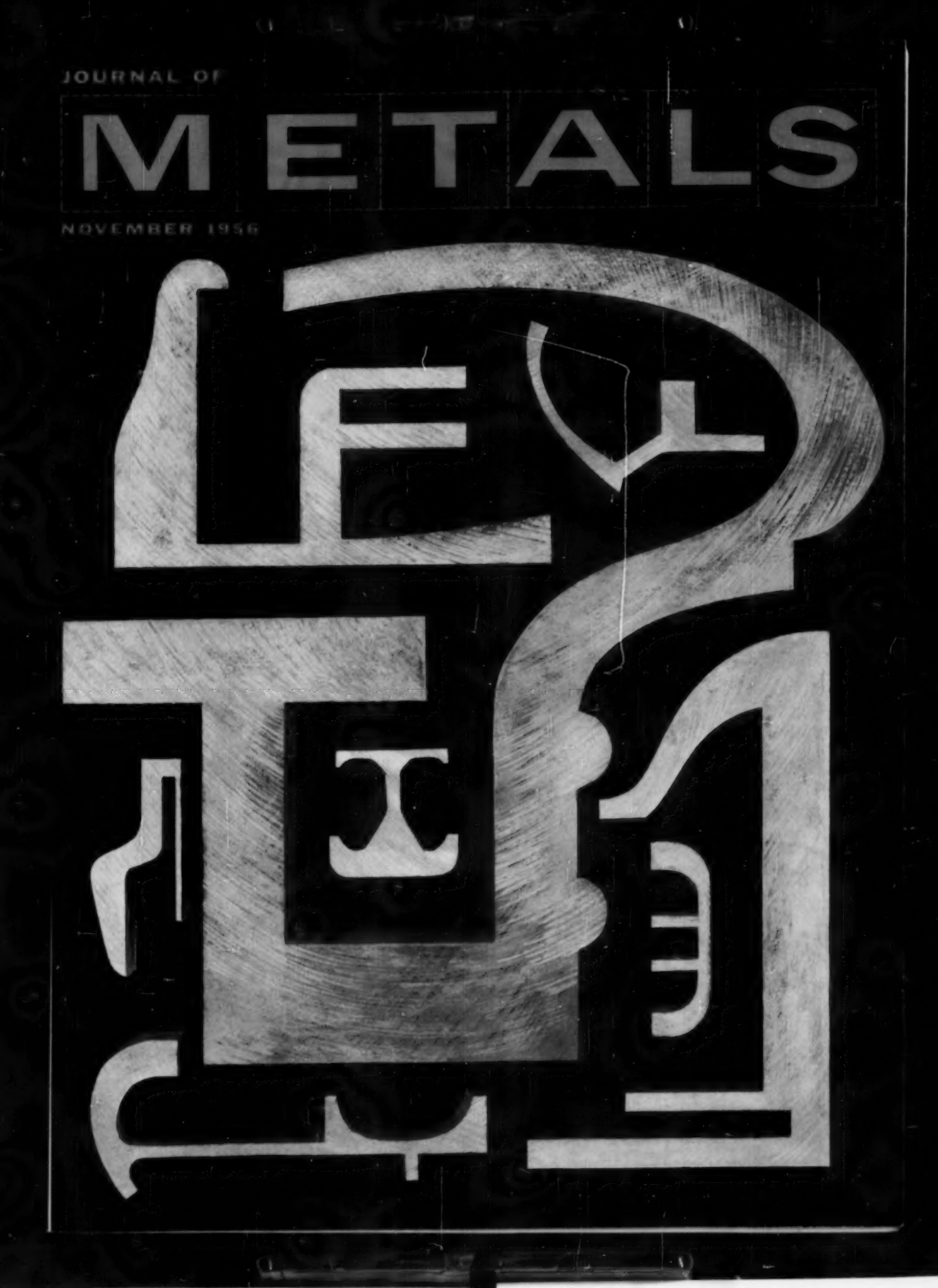
JOURNAL OF

METALS

NOVEMBER 1956



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JOURNAL OF

METALS

VOL. 8, NO. 11

NOVEMBER 1956

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COVER

Artist Harry Brocke depicts a few of the varied shapes being produced by extrusion of aluminum. Extrusion is only one of many developments making possible an astronomic expansion of aluminum production . . . see p. 1526.

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(Continued on page 1590)

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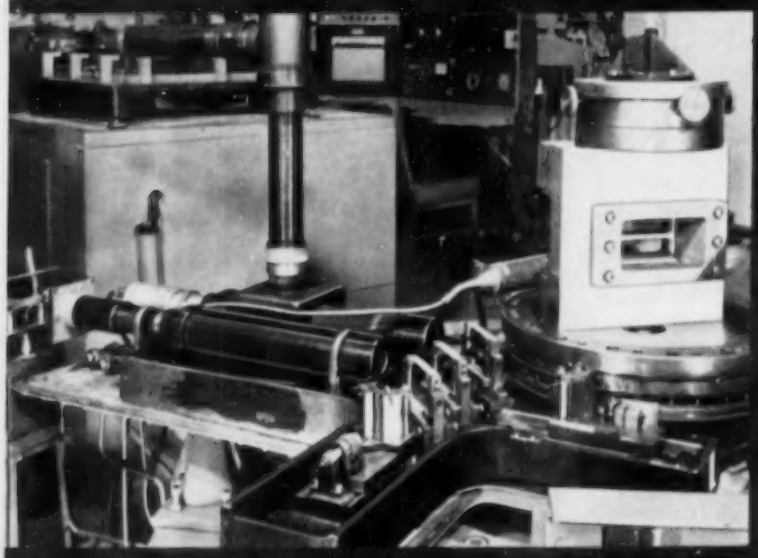

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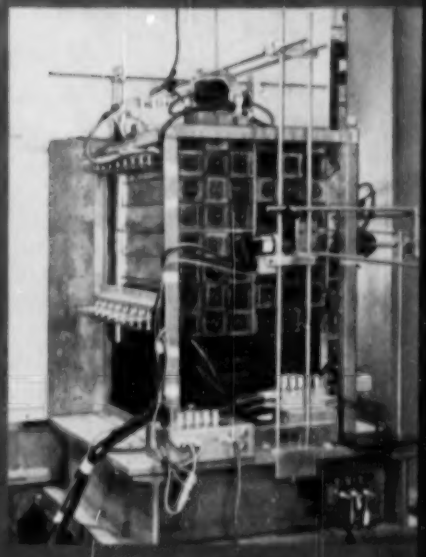

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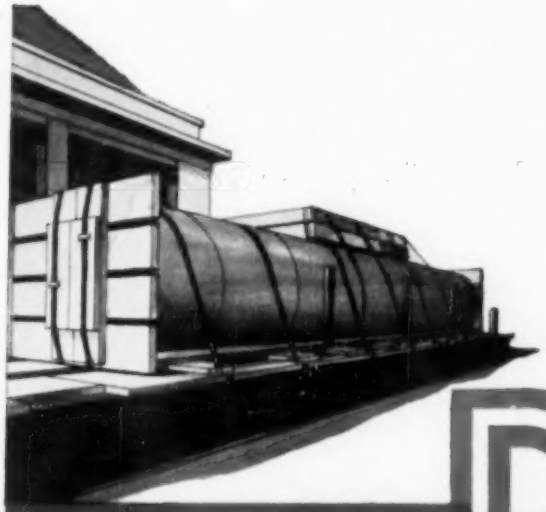

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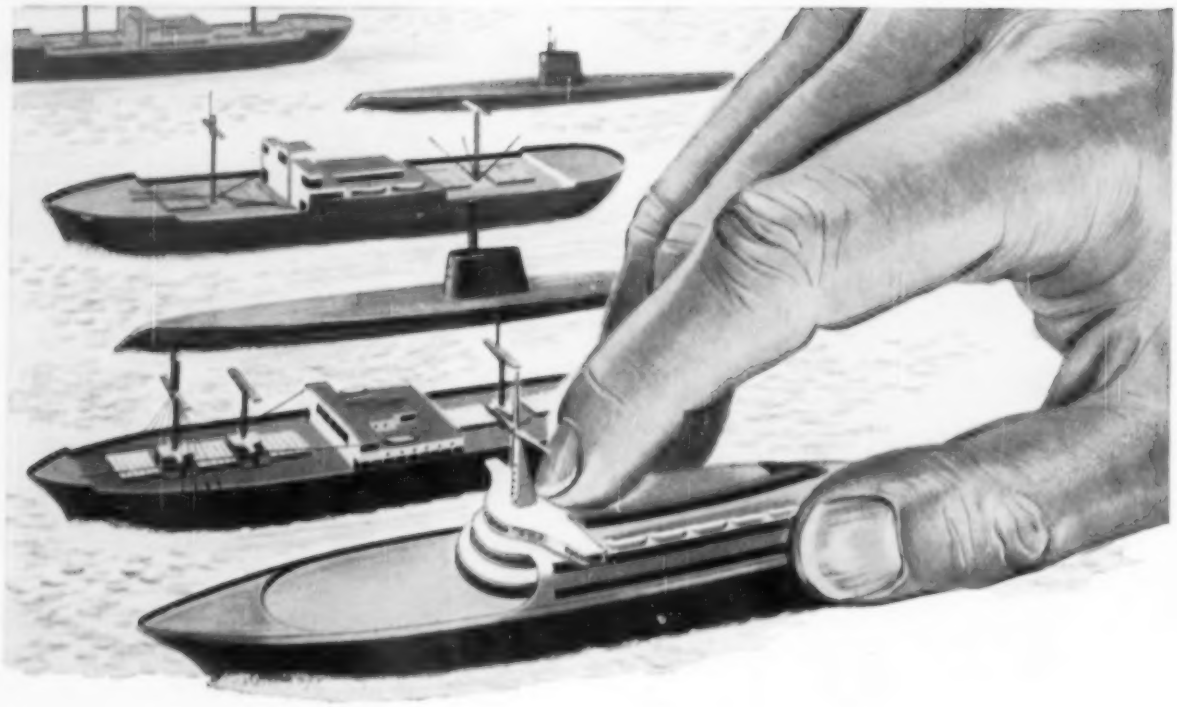

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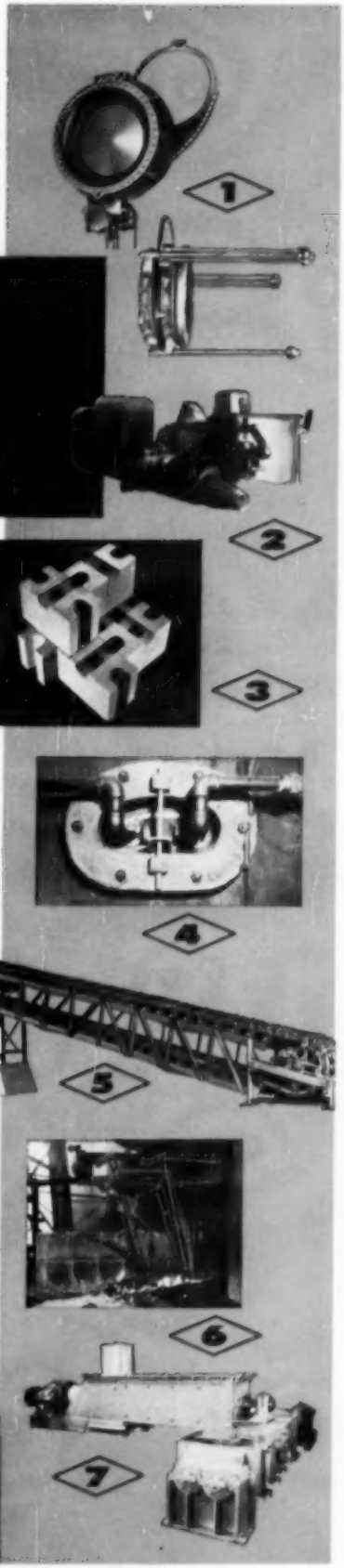

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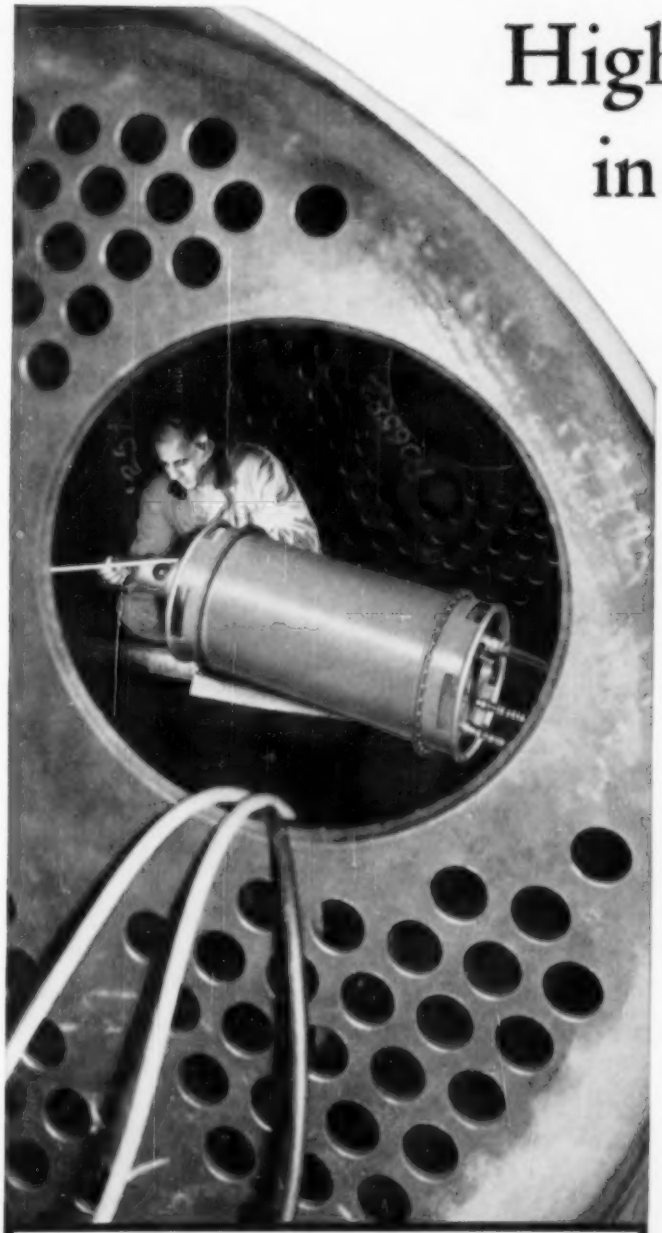

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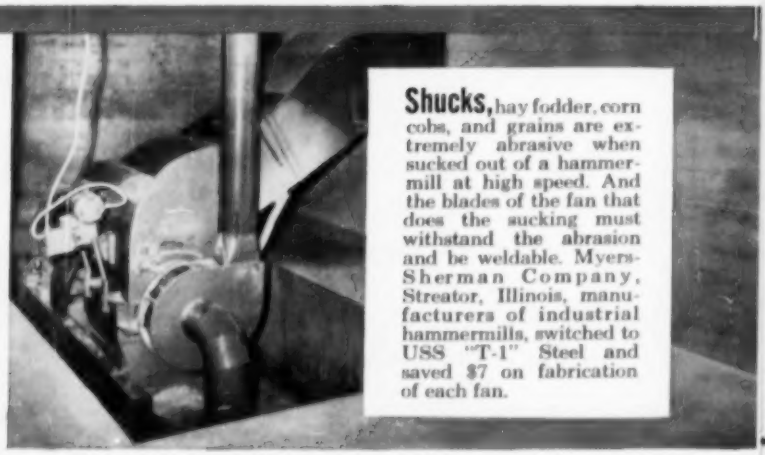
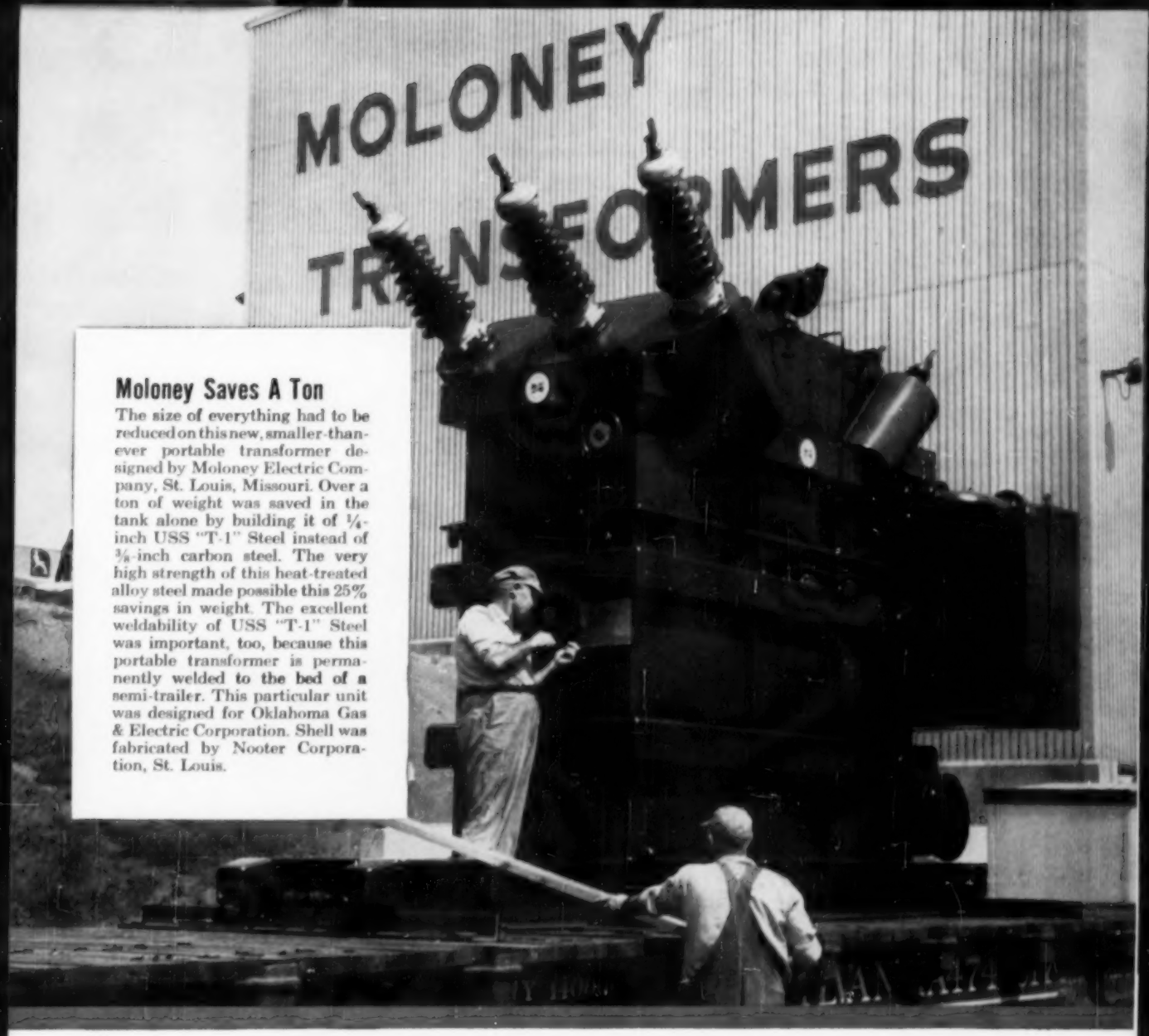


Shucks, hay fodder, corn cobs, and grains are extremely abrasive when sucked out of a hammermill at high speed. And the blades of the fan that does the sucking must withstand the abrasion and be weldable. Myers-Sherman Company, Streator, Illinois, manufacturers of industrial hammermills, switched to USS "T-1" Steel and saved $7 on fabrication of each fan.

Heavier Loads, More Production

Mack Welding Company, Duluth, Minnesota, has used "T-1" Steel to increase the durability and at the same time reduce the weight of its Orange Peel Type, Four Tine Pulpwood Grapples. With these new, lightweight grapples, crane operators can handle increased payloads with present cranes. As a result, production can be increased as much as 40 percent.



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UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS, COAST-TO-COAST · UNITED STATES STEEL EXPORT COMPANY, NEW YORK

USS "T" CONSTRUCTIONAL ALLOY STEEL

USS

SEE The United States Steel Hour. It's a full-hour TV program presented every other week by United States Steel. Consult your local newspaper for time and station.

UNITED STATES STEEL

What are You Looking for

If you are planning to up-grade your product by using a Vacuum Furnace to develop or produce superior metals, here are questions you should ask before buying.

Does the Vacuum Furnace have . . .

---

1 **Hinged door** to conserve floor space . . . assure positive alignment? Provisions for hanging a second door to permit mold set-up work during furnace operation?

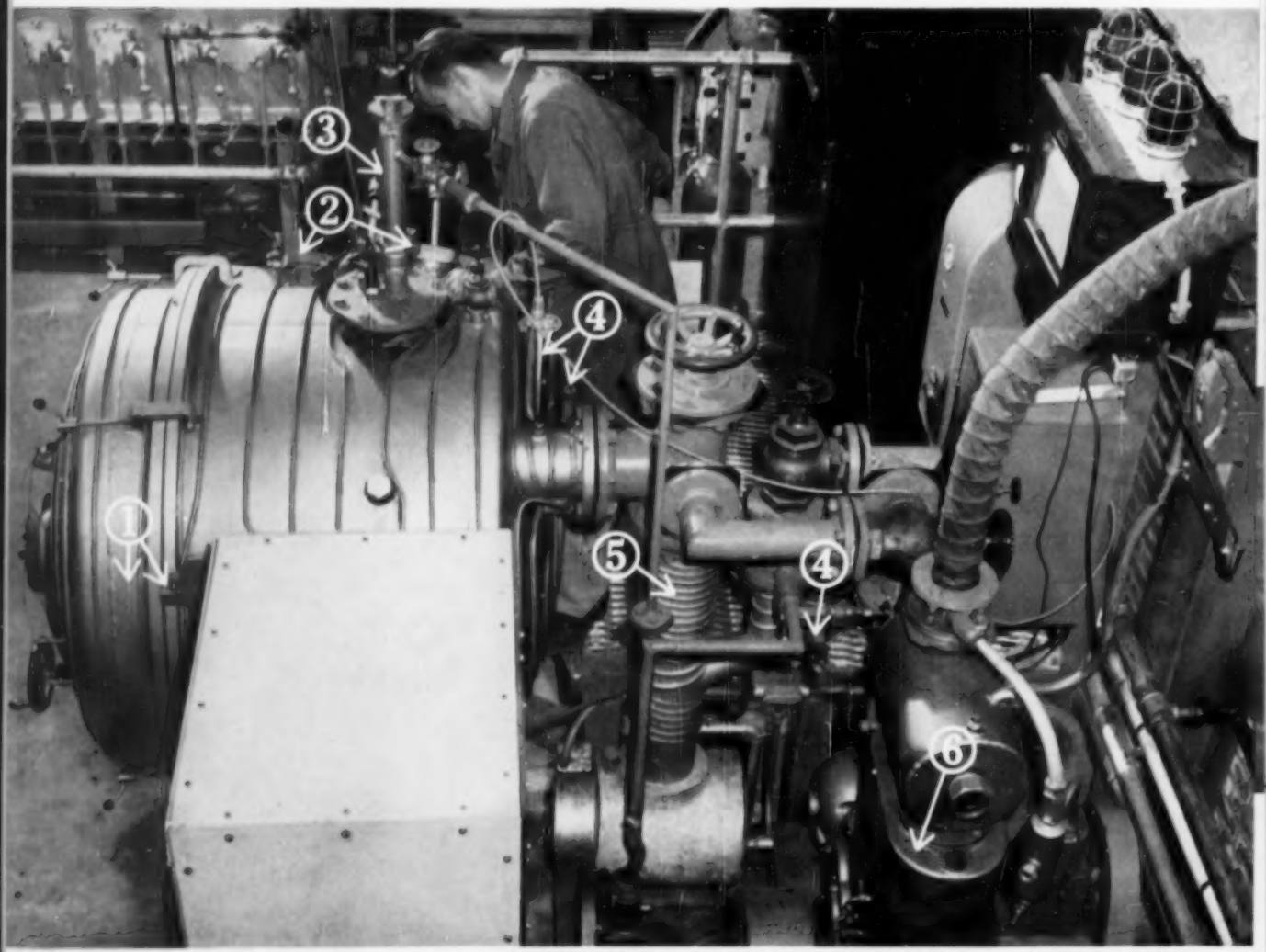
2 **Sight ports** located for ease of operation and equipped with shield and wiper to minimize and remove condensed metallic vapors?

3 **Immersion Thermocouple assembly and air lock** to provide accurate temperature indication for exact process control . . . and to allow retraction and replacement while under vacuum?

4 **Gauging** which resists contamination by condensed vapors from molten bath and provides accurate, reproducible direct reading?

5 High capacity, easy to clean **booster pump** . . . for fast recovery from gas bursts?

6 High capacity **NRC Rotary Gas Ballast Pump** to maintain high efficiency and fast pump down time even on the muggiest days?



First installation for Vacuum Investment Casting. This installation was set up for Austenal Laboratories.

in a Vacuum Furnace?

Vacuum furnaces *can* operate without the features shown below. However, we have learned — from building and operating more high vacuum furnaces than anyone else in the world — that these features more than pay for themselves in terms of safety, flexibility, time, trouble, and money. And these are just some of the special design improvements that NRC engineers can adapt to solve your special problems.

Our years of experience ensure that your NRC Vacuum Furnace will meet your needs as soon as it is installed — and will continue to do so year after year of low cost, trouble-free operation.

Use the coupon below to get your copy of the new NRC Vacuum Furnace catalog

NRC
EQUIPMENT
CORPORATION

7 **Mold turntable** to permit the "split heat" alloy research technique or the casting of several ingots of varied size and shape from a single heat?

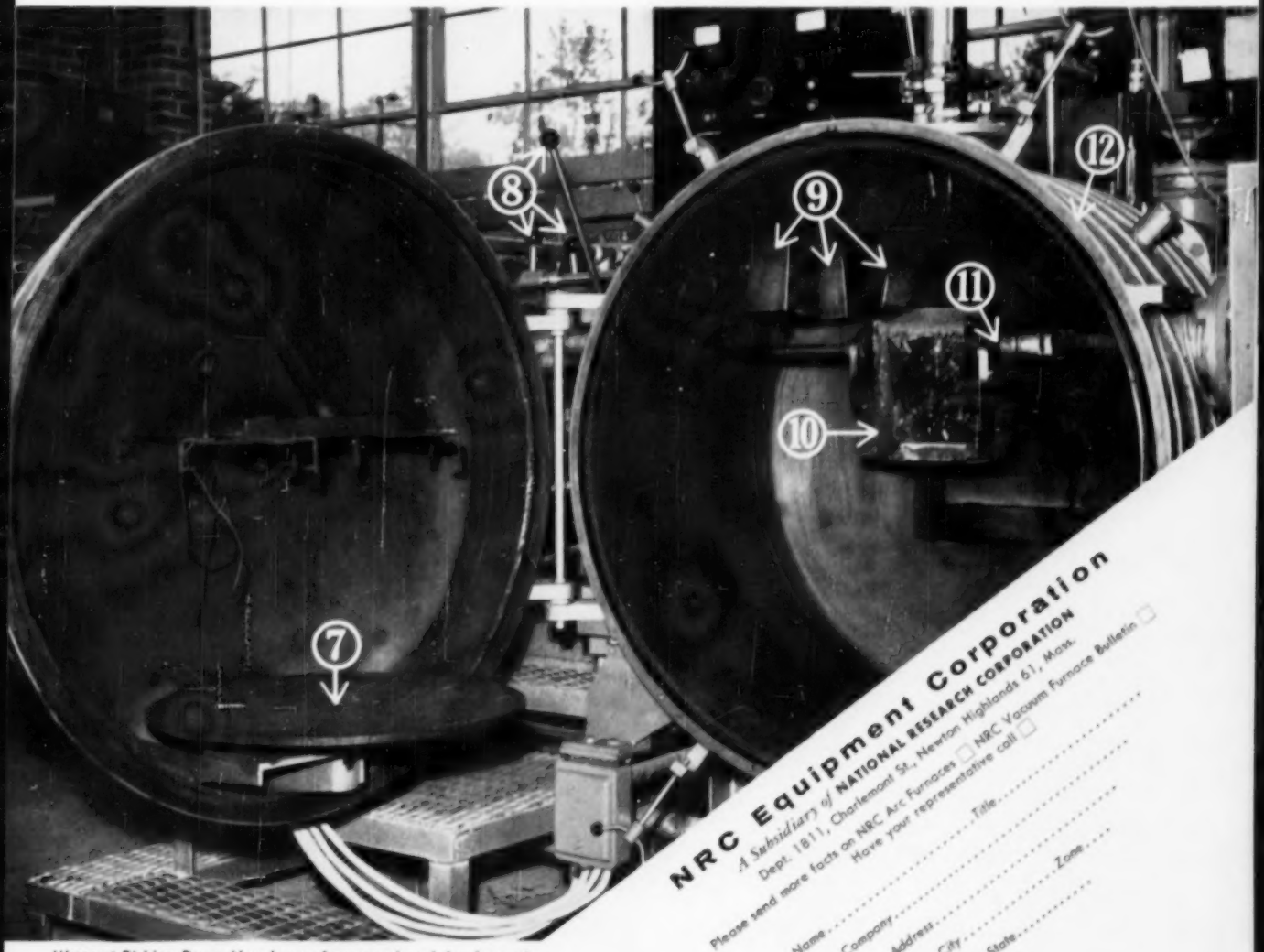
8 Conveniently located **controls** that allow one man to operate the furnace from a central position?

9 **Bulk and alloy charging containers** for using full crucible capacity and to allow late alloying additions for precise control?

10 **Coil** fully insulated electrically to eliminate arcing and resulting dangers of explosions from burn-through?

11 Fast, easy **coil disconnect** from coaxial feed-through to provide rapid, simple crucible change?

12 Large diameter, water cooled, **horizontal stainless steel tank,** for maximum accessibility, flexibility and ease of maintenance?



Microcast Division, Dover, New Jersey, for research and development.

NRC Equipment Corporation
A Subsidiary of NATIONAL RESEARCH CORPORATION
Dept. 1811, Charlemont St., Newton Highlands 61, Mass.

Please send more facts on NRC Arc Furnaces ☐ NRC Vacuum Furnace Bulletin ☐
Have your representative call ☐

Name.....Title.....
Company.....
Address.....
City.....Zone.....
State.....

Coke quenching car, Youngstown Sheet and Tube Co., Youngstown, Ohio. Ductile iron plates, doors, diaphragms, and door hinge brackets have greatly extended the service life and reduced maintenance costs on cars of this type. The castings were held in place with rivets of "Yoloy", a nickel-copper steel produced by Youngstown.

Service life extended...

Hopper car survives coke quenching ordeal five times longer with Ductile Iron

This hopper car is on a sizzle cycle at the Brier Hill coke plant of Youngstown Sheet and Tube.

It totes 9 ton loads of 2000°F. coke from oven to cooling tower for water spray quenching. Round the clock. Seven days a week.

Despite these punishing abrasive and oxidizing conditions, ductile iron end and back plates, fastened with Yoloy steel rivets, were still serviceable after 18 months' service. *That's nearly five times the life of 1½" boiler steel plates previously used.* No warping. No cracking. Limited scaling.

A second comparative test – this time on the hopper doors – showed ductile iron lasted three times longer than gray iron. Result: Youngstown now standardizes on ductile iron for all parts that come in contact with hot coke.

Maybe ductile iron is the answer to your hot application problem, too. At high temperatures, it offers excellent resistance to growth, warpage and oxidation. It's strong and tough. Combines many advantages of both steel and cast iron. Proven successful for furnace doors, grates, pouring troughs and the like.

Want to know more about this new material? Write for "Ductile Iron, The Cast Iron THAT CAN BE BENT." Gives full particulars on Heat Resistant Ductile Iron and the entire Ductile Iron family.

ductile iron . . . the cast iron that can be twisted and bent

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street, New York 5, N. Y.

Aluminum Strides Forward

With aluminum outdoing itself as a dynamically expanding industry in the U. S.—p. 1526—Canada, ranking second only to the U. S. among the world's aluminum makers, is continuing to move forward in this ever widening market. Using abundant hydroelectric power in Quebec and British Columbia, Canada produces aluminum from Caribbean bauxite ores, which are processed into alumina prior to ocean shipment. The country's present capacity, reckoned at 732,000 tons, is expected to reach some 1,100,000 tons by 1960. Of this, more than one million will be operated by Aluminum Co. of Canada, who is expanding its Kitimat, B.C., plant from 150,000 to 330,000 tons, and adding 150,000 tons of new reduction capacity in the Saguenay Valley of Quebec. British Aluminium Ltd. is entering the field in Canada with the construction of an 80,000-ton reduction works at Baie Comeau, Quebec . . . But the U. S. and Canada are not alone in aluminum expansion plans, and tremendous strides are being taken to extend aluminum capacity throughout the world.

Plan First U. S. Magnesium Plant Built Since War

Since U. S. demand for magnesium dropped off at the end of World War II, metallic magnesium has been produced in this country from sea water by The Dow Chemical Co. at its 25,000-ton Freeport, Texas, plant and at the government-owned 50,000-ton Velasco, Texas, plant. Extended use of magnesium as a reducing agent for titanium and zirconium, as well as increased use of magnesium photoengraving plates, has given impetus toward expanding magnesium facilities. Now a second producer, Alabama Metallurgical Corp., has laid down plans for a 10,000-ton works, utilizing ferrosilicon reduction of dolomite. Plant to be built on the Alabama River near Birmingham, is a joint project of Brooks & Perkins Inc., a Detroit fabricator of magnesium, and Dominion Magnesium Ltd., owner of a ferrosilicon magnesium reduction works in Canada.

Columbium and Tantalum Take Wings

With the age whirling into faster supersonic speeds, new and heretofore practically unused metals are required. Columbium is finding its place in high temperature alloys, but it is generally found closely associated with tantalum, a metal whose uses include a score of electronic devices. Separation has been accomplished only with great difficulty, but a new method, making use of a selective solvent extraction technique, has recently been developed by U. S. Bureau of Mines . . . Molybdenum Corp. of America reports that government stockpiling has been completed. The Dept. of Defense has been requested to study military requirements of the two metals . . . Industry seems optimistic about their future, and Fansteel Metallurgical Corp. has announced plans for a new $6 million plant for production of tantalum and columbium. The firm's present expanded works at North Chicago, Ill., is reportedly unable to meet the growing demand.

A wink built for speed!

The speed of a wink varies, depending upon its purpose . . . and its target. The femme fatale's provocative wink from the dim recesses of a cocktail lounge may pack the wallop of a Sabre-Jet, yet its speed is a languorous one-tenth of a second. Imagine a wink five hundred time as fast! Fairchild Camera and Instrument Corp. has produced a camera that does just that. Its shutter speed is 1/5000th of a second . . . a speed made possible only by using Titanium shutter leaves. Such shutter speeds are essential in guided missile research and the development of supersonic devices.

Titanium had the necessary light weight, rigidity, fatigue resistance, corrosion resistance and capability of being rolled to a thickness of 0.0022" with a tolerance of ± 0.0001".

Just one of the many jobs being done better with Titanium.

TMCA is the world's major supplier of Titanium bar, billet, sheet, strip, wire, extrusions and tubing to jet engine, guided missile, atomic energy, chemical processing and marine industries.

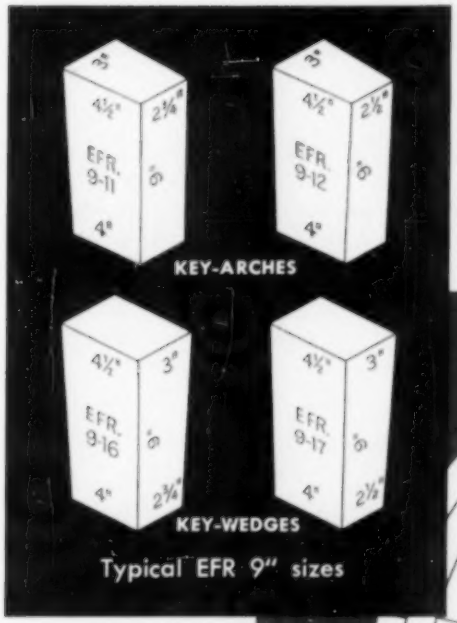
. . . FIRST IN **Titanium**

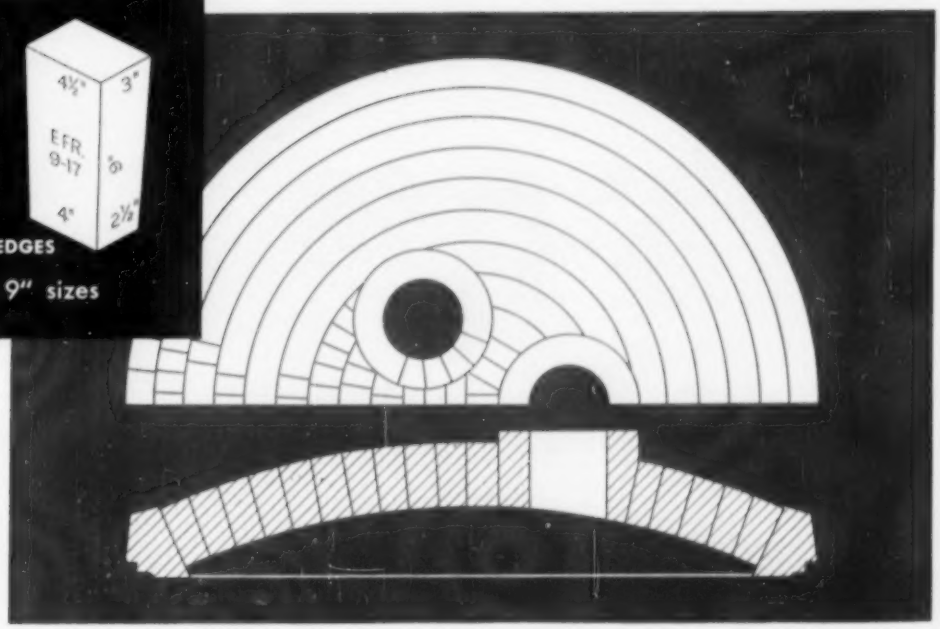
TITANIUM METALS CORPORATION OF AMERICA, 233 Broadway, New York 7, N.Y.

For electric furnace roofs

Harbison-Walker EFR design

provides important benefits





Harbison-Walker EFR (electric furnace roof) brick are modified 9″ key-arches and key-wedges, designed for use in combination with a large proportion of standard 9 x 4½ x 3″ sizes in the construction of roofs of any diameter and rise.

The use of these EFR shapes insures a close fit of the brick and roof construction of best workmanship.

The number of different sizes required for building a roof with the aid of the EFR brick is greatly reduced for some designs.

Bricklaying is simplified and much time is saved when EFR brick are used.

EFR brick are power pressed by which method of forming all of the most desirable physical properties are secured.

Roofs built of smaller brick units in preference to large special shapes generally prove to be more serviceable. The smaller sizes are more resistant to thermal shock.

The EFR shapes cost less than large special shapes and since they are used with standard 9″ sizes in predominance, the overall cost is considerably reduced.

H-W High Alumina Castable and Korundal Ramming Mix sometimes are used to advantage as a monolith to facilitate easy fitting in the center section.

The EFR brick, together with the standard 9″ sizes needed for complete roofs, are furnished in the types and classes of refractories best suited for the various operating conditions. For example, they are made in the following brands: STAR and VEGA silica brick; H-W MULLITE; KORUNDAL; and various Harbison-Walker superduty brands, such as ALAMO and H-W SUPER SAVAGE.

The combination of quality, H-W Technical Service and balanced selection based on availability of all types and classes of refractories from one source, provides maximum economy.

HARBISON-WALKER REFRACTORIES COMPANY

AND SUBSIDIARIES

World's Most Complete Refractories Service

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- Industrial X-ray Fluoroscopes
- Industrial Image Intensifiers with Closed Circuit Television

Norelco®

FIRST RAPID AUTOMATIC

Element

Norelco's new Autrometer is capable of an incredible analysis load in rapid production quality-control. Whenever quantitative assays of compounds are necessary to determine composition constancy and production stability, the Autrometer is invaluable. It permits virtually instantaneous checks of repetitive samples. Speed of analysis varies slightly with different elements but remains *better than fifty times faster than chemical analyses.* This facility provides continuous checks—results in greater product uniformity.

The Norelco Autrometer is a fully automatic multi-indexing X-ray spectrograph, delivering printed qualitative and quantitative data on as many as twenty-four elements in a single sample. Every element selection may be made—magnesium (atomic #12) through the entire range of heavier

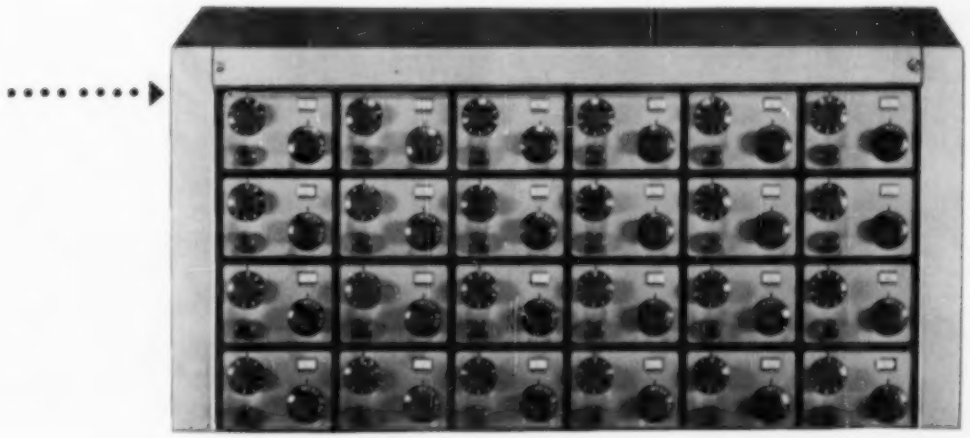
NORTH AMERICAN

750 SOUTH FULTON

In Canada: Rogers Majestic Electronics Ltd.,

PRODUCTION X-RAY PROCESSING ANALYZER

Determinations 50x Faster



elements.

Accurate determinations can be made from trace amounts to 100% of a given element—in a matter of minutes without necessity of film or plate standardization or processing techniques. The equipment is readily operated by laboratory personnel.

Numerous specimen accommodation features are found in the advanced mechanical design. Stainless steel sample holders, mylar windows, gravity loading, positive reference plane positioning and liquid, powder or solid sample facilities—provides universal adaptability.

Extreme accuracies and reproducibility; savings in time, man-hours and money, as well as the non-destructive character of X-ray analysis—are exclusive Autrometer features.

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Manganese helps ease the squeeze on Stainless Steel!

METALS DO MORE ALL THE TIME

Important facts about a new and plentiful family of low-nickel Stainless Steels!

Now in plentiful supply, the new "200" Series Stainless Steels permit steelmakers to greatly expand their output of Chrome-Nickel stainless from existing nickel supplies. With the addition of manganese, the nickel content can be cut in half to provide practical, workable stainless steels that can be applied to a wide variety of uses.

The "200" Series is meeting the constantly expanding needs of the transportation, building, manufacturing and many other fields. It's becoming increasingly popular for use in kitchen utensils, appliances, truck bodies, trains, automobile trim, hospital equipment and scores of other consumer products.

For further information, see your stainless steel supplier, or write ELECTROMET—leading producer of chromium, manganese, and more than 100 alloys for the steel and other metal industries.

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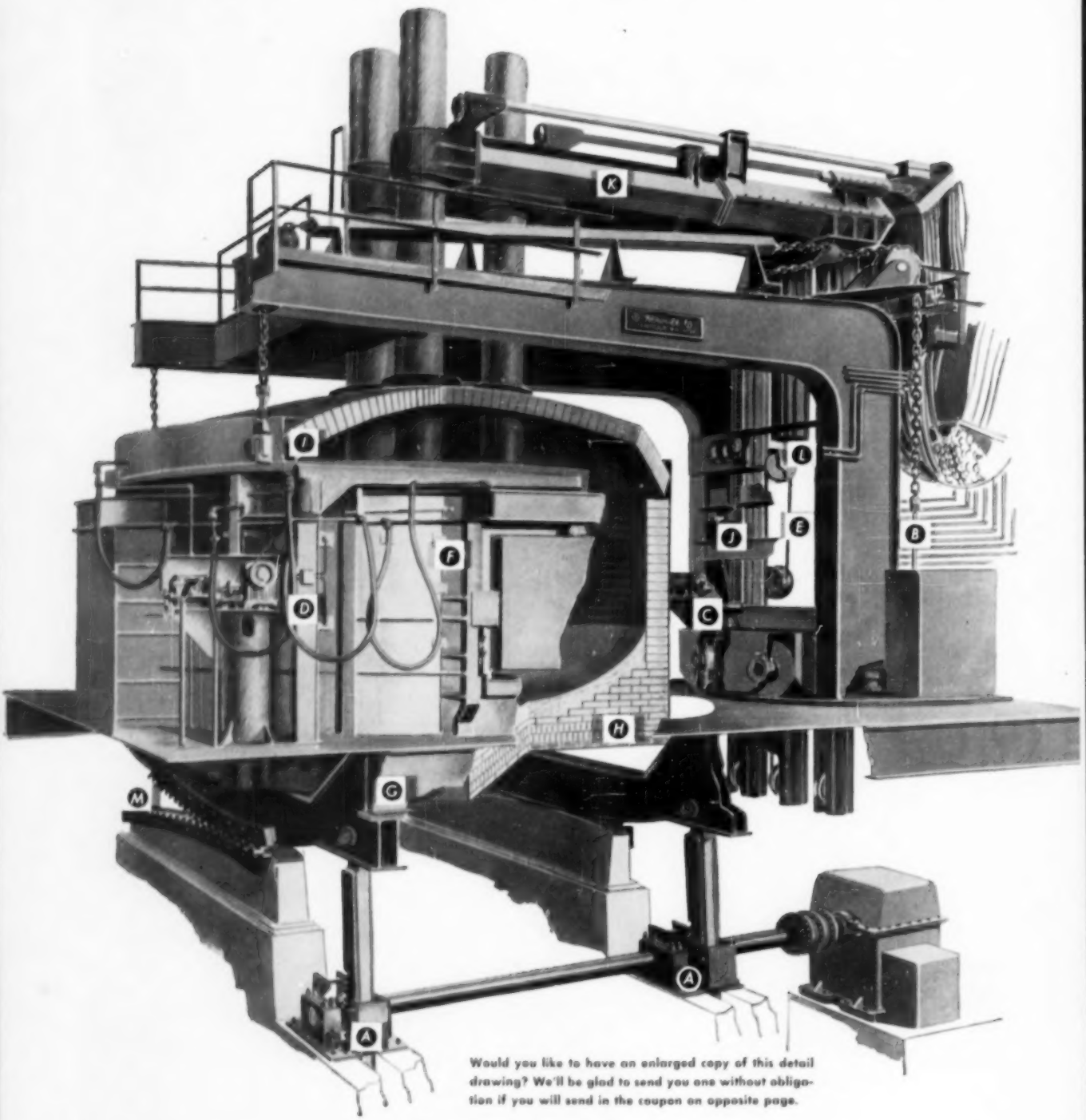
. . . THANKS TO ALLOYS

Ten (10) reasons why

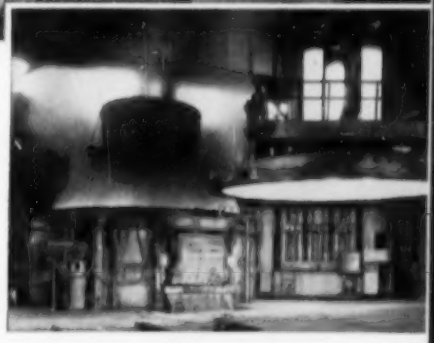
is the finest electric furnace



Would you like to have an enlarged copy of this detail drawing? We'll be glad to send you one without obligation if you will send in the coupon on opposite page.

We welcome *an opportunity to help you select and install the Heroult Furnace best suited to your requirements. Remember—the Heroult we make and install for you will be the finest electric melting furnace that money can buy!*

the NEW Heroult on the market!



To HELP YOU PRODUCE better quality steel faster and more economically, we have made important design improvements in the long-famous Heroult electric melting furnace. Five of the features shown in the cutaway drawing at the left and described below are to be found *only* in the new Heroult. *All ten* of the illustrated features are important to those interested in the most modern melting equipment. Any way you look at it—performance efficiency, operating economy, or low-cost maintenance—this *new* Heroult is unquestionably the *finest* electric melting furnace on the market.

1. The Heroult Furnace is *the only 100% mechanically operated electric furnace.*

It includes such mechanical features as: (A) heavy rack-and-pinion-type tilting mechanism, (B) mechanical roof lift, (C) motor-driven, rotating, jib-type roof swing, (D) winch-operated, water-cooled, jib-type door-lifting mechanism, and (E) high-speed, electro-mechanical electrode-positioning mechanism.

2. *Another exclusive* — Cage-type shell construction with shell plates loosely attached (F) to a heavy supporting structure.

This construction minimizes shell warping and allows easy replacement of damaged shell plates.

3. *Exclusive*—Operating mechanism independently supported.

The tilting platform on which all operating mechanisms are supported is attached directly to the rockers independent of the shell structure (G). Thus operating mechanisms are unaffected by any shell distortion.

4. *Exclusive*—Flat Bottom Shell.

This feature (H) facilitates easy shell relining and provides maximum protection against burnouts. Thicker refractory at the sides of the hearth promotes more uniform bath temperature.

5. *Exclusive* — Water-cooled, Skew Back Roof Ring.

This feature (I) eliminates the need for special skew-shaped roof refractories.

6. Electrode Mast Safety Device.

This spring-loaded, rack-and-pawl-type device (J) provides positive protection against damage resulting from electrode winch cable breakage.

7. Square-Section, Water-Cooled Electrode Mast Arms.

This design (K) guarantees a rigid connection between mast and mast arm, thus helping to maintain proper electrode position.

8. Remote-Controlled Electrode Clamps.

This device, of the spring-clamp, air-release type, is located inside of the rear section of the water-cooled mast arm where heat cannot affect it.

9. Square-Sectioned Electrode Mast.

This design feature (L), developed by American Bridge, assures proper guiding and electrode positioning.

10. Rockers.

The heavy fabricated steel curved top and bottom rockers (M) minimize forward travel during tilting. These rockers are so designed that the furnace will tend to return to horizontal position from any degree of tilt.

THE NEW

Heroult

ELECTRIC FURNACES

are available in:

—sizes of shell diameter ranging from 7' 0" up, and with capacities of from 6,000 lbs. up to 400,000 lbs. and greater. They are equipped with roof-removing mechanism to permit fast top charging. They can readily be furnished with a non-magnetic shell bottom section to accommodate induction-stirring equipment.

Gantry-type top-charge furnaces, door-charge furnaces, and special furnaces for duplexing and non-ferrous melting can also be supplied.

Heroult
ELECTRIC MELTING FURNACES

Send coupon for catalog and/or enlarged copy of detail drawing with special installation and engineering data.

American Bridge Division
525 William Penn Place, Dept. JM-116
Pittsburgh 30, Pa.

Please send me a copy of the latest Heroult Electric Furnace catalog ( ) and/or your new folder showing large drawing with special installation and engineering data ( ).

Name ..... Title .....

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UNITED STATES STEEL

Columbium

by MCA

permits design engineers and metallurgists new latitude, the wide-open throttle

Alert design engineers may once more avail themselves of the special properties of columbium without fear of inadequate supplies. Severe requirements for highly stressed parts (such as turbine blading and exhaust manifolds) demand the best material, not near-substitutes.

The future promises more exacting demands, and engineers have been quick to recognize the help they can get from columbium to enhance high-temperature strength and corrosion-resistance.

MCA, in manufacturing columbium products, pledges the same high quality and uniformity that has distinguished MCA tungsten, molybdenum, boron and rare earth alloys and chemicals . . . to meet fully your specifications, with the usual excellent service and delivery. Write today.

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MCA

DOW

Dow high temperature magnesium alloys have excellent fabrication characteristics

Lightweight structural metals with high strength, stiffness and elasticity at elevated temperatures! A new group of Dow magnesium alloys offers a great combination of these properties without the fabricating difficulties normally experienced with other high temperature materials.

Specially developed for use in airframes, missile and engine structures, the new alloys are already making weight reductions possible for several manufacturers. These alloys show advantages at temperatures up to 700°F. Limited test data on properties up to 800°F. are available for some of them.

FABRICATION: Fabrication characteristics are equal to those of standard magnesium alloys.

WELDABILITY: 95 to 100% weld efficiency at elevated temperatures.

FORMABILITY: Single deep draws can be easily accomplished.

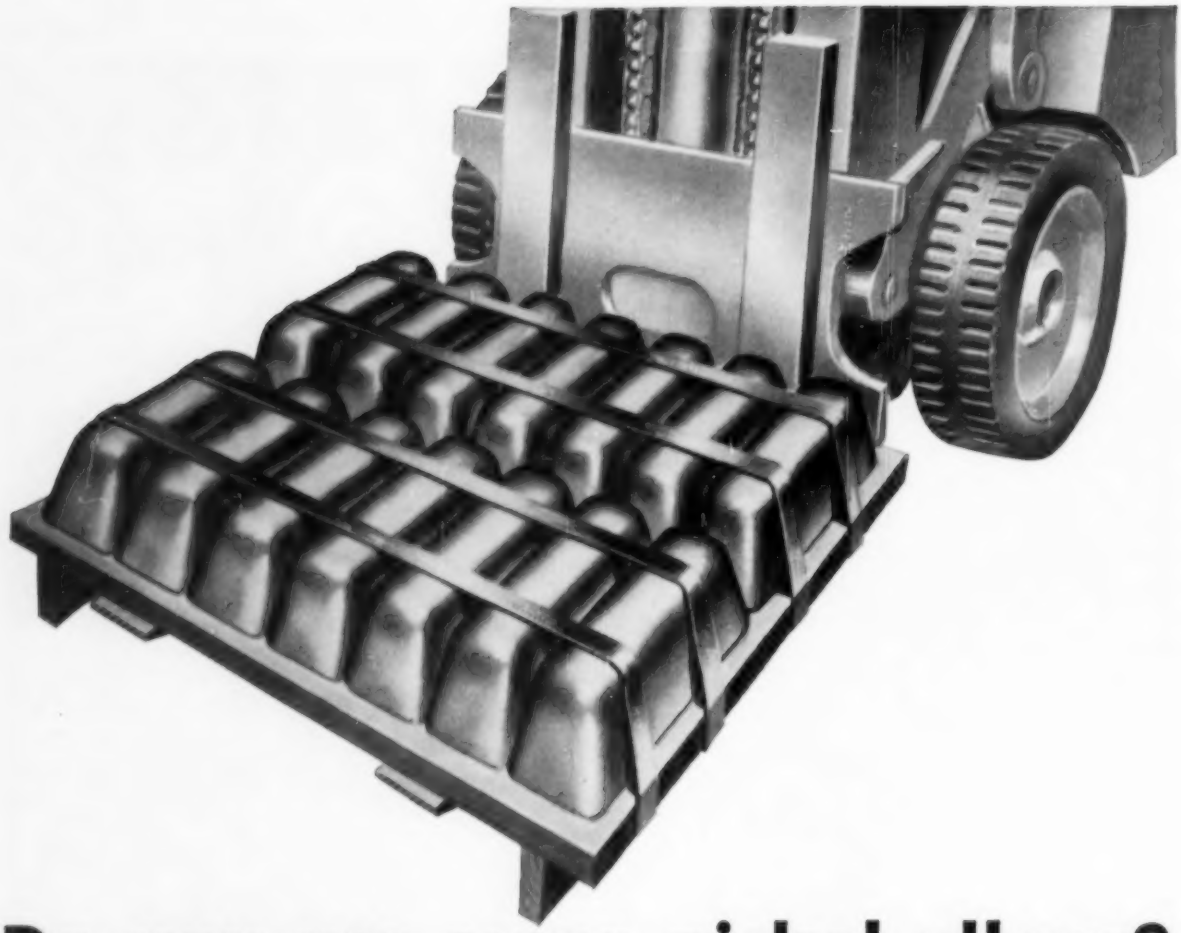
MACHINABILITY: Best machining characteristics of any structural metal.

One of the new alloys is magnesium-thorium composition HK31A. It is now available in rolled form from stock. Castings and sheet in mill quantities are also readily available. A companion alloy for extruded shapes and forgings will soon be in production.

For more information about the new high temperature magnesium alloys, contact your nearest Dow Sales Office or write to THE DOW CHEMICAL COMPANY, Magnesium Sales Department MA 362E, Midland, Michigan.

EASILY FORMED. These HK31A parts were drawn using production dies and processes for standard magnesium alloys. The parts retained a higher percentage of original properties than standard alloys.

you can depend on DOW MAGNESIUM DOW



Do you use scrap nickel alloys?

Here's a better source of raw material!

ALLOYMET NICKEL BASE pig and shot* are better than scrap nickel alloys in every way — yet they are available to you at only 5% more.

Alloymet pig is easier to store and handle, and melting loss is minimized. Because every heat in each shipment carries a notarized laboratory analysis, you are in effect insured against contamination.

Compare our alloys with scrap in actual use. Discover why its use will more than repay you for the slight premium in cost.

**Alloymet available in a complete range of nickel chrome, nickel iron and nickel copper analyses.*

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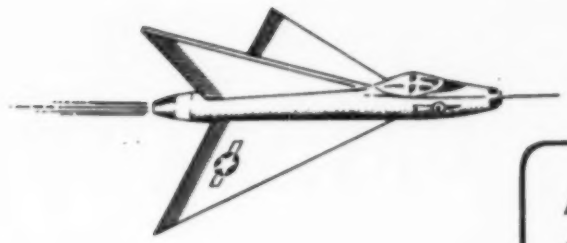
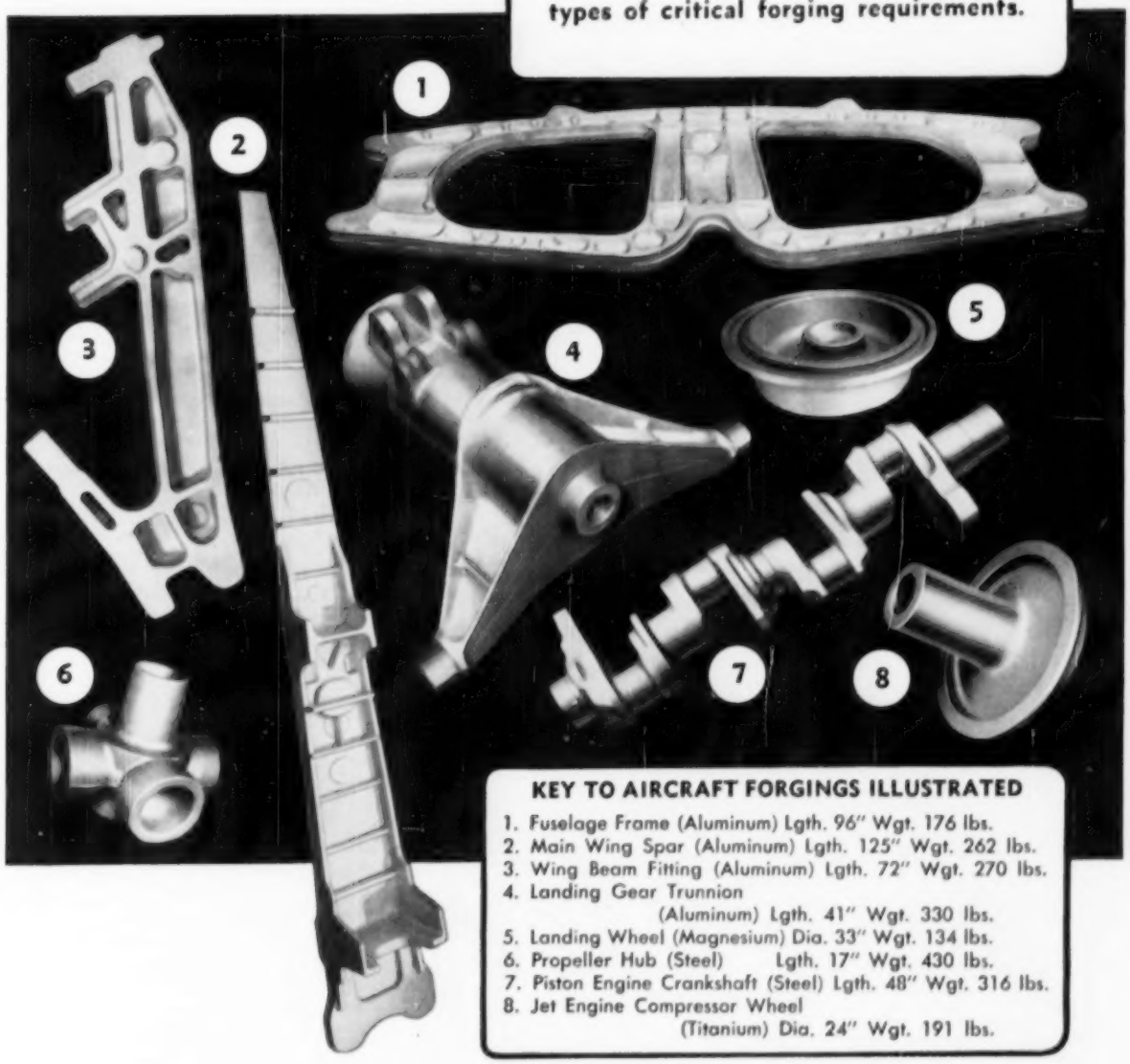


DEPENDABILITY...

Aviation engineers and designers since the beginning of the Aircraft Industry have relied on Wyman-Gordon for all types of critical forging requirements.



KEY TO AIRCRAFT FORGINGS ILLUSTRATED

1. Fuselage Frame (Aluminum) Lgth. 96" Wgt. 176 lbs.
2. Main Wing Spar (Aluminum) Lgth. 125" Wgt. 262 lbs.
3. Wing Beam Fitting (Aluminum) Lgth. 72" Wgt. 270 lbs.
4. Landing Gear Trunnion (Aluminum) Lgth. 41" Wgt. 330 lbs.
5. Landing Wheel (Magnesium) Dia. 33" Wgt. 134 lbs.
6. Propeller Hub (Steel) Lgth. 17" Wgt. 430 lbs.
7. Piston Engine Crankshaft (Steel) Lgth. 48" Wgt. 316 lbs.
8. Jet Engine Compressor Wheel (Titanium) Dia. 24" Wgt. 191 lbs.

WYMAN-GORDON COMPANY

Established 1883

FORGINGS OF ALUMINUM • MAGNESIUM • STEEL • TITANIUM

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ZIRCONIUM-MAGNESIUM MASTER ALLOY

INCREASED STRENGTH

AT ELEVATED TEMPERATURES

Light magnesium alloy castings will gain high impact strength at elevated temperatures when Zirconium is added. TAM's Master Alloy provides a most efficient method. Notch bars are readily soluble in production heats. Recoveries are high.

In addition to greater impact strength at elevated temperatures, a tough fine grain structure is produced . . . relatively free of contamination. It is readily castable or extrudable, with minimum microporosity or microshrinkage. It resists corrosion.

Foundrymen prefer TAM Master Alloy for its ease of handling and storing as well as its freedom from obnoxious fuming.

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DRIFT

Industry Impact on the Research Pattern

INDUSTRIAL research has come a long way from the days of the backroom or kitchen-sink lab. Extensive facilities, varied staff, even glamour have become prominent ingredients of laboratory installations, highlighting the modern industrial research program. People who have ideas are basic, but much recent emphasis has been placed on making the surroundings as favorable as possible for attracting and holding top people.

A pattern seems to have developed in the architectural handling of the buildings themselves. Often the structure has an administrative and reception core in a multistory section at the front of the building, with the working areas extending back from this office building facade. (And, usually leaving plenty of room for expansion to the rear of the original unit.) If the program calls for pilot plant work the structure as a whole often resembles a taller, shallower block fronting the lower, simpler pilot plant or testing section. Locations chosen also fit the overall aim of designing for pleasing appearance as well as function. Landscaped settings in locations that also provide nearby and adequate staff housing usually equate to a suburban location when other factors are added.

The suburban site may be logical for many research centers, but sometimes the community being honored has strong reservations about the prospect of a business neighbor. The *Cleveland Plain Dealer* had this to say on the problem: "The best answer to resistance to research laboratories which still pops up in some suburban communities is a close look at a handsome new one like Union Carbide's in Parma. (Ohio)."

". . . The new Carbide (actually National Carbon Div.) lab is a beauty. Both inside and out it is far more like a university than an industrial center . . . One look at this center should be enough to convince anyone that a research laboratory is an excellent neighbor." (See JOURNAL OF METALS, November 1956, page 1530.)

If there are obvious trends in research building design and site selection, there are less obvious but more important trends in the organization of research programs. As the quantity of activity grows by leaps and bounds, there is a tendency to separate levels of activity. Labels vary—fundamental, basic, applied, developmental, product design—yet the pattern is about the same: A tendency to place company-wide fundamental research work at one permanent installation away from mills and plants, while placing the applied levels in the closest possible contact with production. In other words, a separation of long range and short range research activity is taking place. The aim, to place each in the atmosphere best suited for it.

TODAY, then, there are three sources of organized research activity as industry takes its place alongside the traditional sponsors: schools and government. What of the role and stature of this newest partner, industrial research? J. A. Krumhansl of National Carbon puts it this way, "If there is a single prominent feature of the present vigorous expansion of industrial research that strikes one, it is the broadening of *scope* as well as increase in volume which is taking place."

Part of this growth in scope undoubtedly comes from the increased emphasis on physics in various forms such as chemical physics, biophysics, and solid-state physics. All of these titles are illustrations of the "boundary-destroying nature of the physicist's viewpoint," to quote J. A. Krumhansl again. But one must look a little farther on the practical side to find why company management is willing to go into fields where byways are as likely to develop as are ideas along the mainstream of the company.

Diversification and the desire for more diversification is probably providing major impetus for the change in management viewpoint required to make it receptive to fundamental research activity that may lead in almost any direction. If one is only interested in making widgets, research that may lead to making gadgets, instead, is not attractive. If one would like to diversify, why, then, diversification stemming from research may be even more attractive than diversification via absorbtion of companies and products.

To have some idea where this type of thinking may lead, when backed up with major expenditures, we can do no better than quote from Mr. Krumhansl again: ". . . the great advance in applications follow as surely as day and night from the exploration of new basic areas, and this is the broadening in scope that was referred to in the beginning of this discussion. Although contributions to science in an altruistic sense will certainly result from the basic research we do here, our ultimate purpose is the certain expectation that basic research pays off in commercial prosperity and continual broadening of our product, material, and process line."

— R. A. Beals

Aluminum Comes of Age

New Market for Aluminum?

Torrance, Calif. . . Formation of a new division to engineer, fabricate, and erect aluminum structures has been announced by Harvey Machine Co. Structurals will be produced on the plant's 8000 and 12,000 ton extrusion presses. This is the first time that aluminum structurals, comparable in size (e.g. 16-in. WF) and cost to structural steel have been made available for immediate delivery.

JUNE 1952—*Resources for Freedom*, more commonly called the Paley Report, with regard to aluminum predicted . . .

"A demand in the neighborhood of 4.5 million short tons by 1975, or nearly five times the level of consumption of 1950, is considered plausible. Old scrap can be expected to constitute an increasing proportion of supply, so that by 1975 it may furnish 20 pct of total consumption as contrasted with 10 pct in recent years. Accordingly, the projected United States demand for primary aluminum in 1975 might be about 3.6 million short tons or about four times consumption of primary aluminum in 1950."

"Fantastic" was one comment . . . "A very optimistic prediction" was a common response. But there were others who felt that this was a reasonable estimate of the future of this metal, which in a span of 65 years came from nowhere to a place alongside copper, lead, and zinc. They were right, and the graph shows that since 1952 aluminum consumption has been greatly in excess of that anticipated by this report.

Indeed, demand seems to be mounting at such a rate that yesterday's optimistic predictions soon fall into the category of pessimistic estimates. And just recently two leading aluminum producers made predictions for 1965 and 1975, each in excess of the 1952 Paley prediction.

The prewar's *pot metal* suddenly became a vital material for aircraft in 1940. Postwar years showed some drop in consumption, but soon a multitude of civilian uses began to demand ever increasing quantities . . . the rapidly growing construction market, electric power transmission, the transportation field, appliances for household use, collapsible containers, a variety of die castings, and foil for packaging.

Not only has aluminum been entering into new uses, but also it has been substituting for other metals, notably copper and zinc. The supply of aluminum can continue to increase without serious increases in cost, and this feature is powerfully at work. Whereas aluminum was, over most of its short commercial life, considerably more expensive than copper and much more expensive than lead and zinc, it is now cheaper by weight than these and much the cheapest by volume.

The expansion of primary aluminum capacity can be expected to be accompanied by a roughly proportionate increase in the industry's demand for electric power, but this is not expected to create any great problem. In the late forties the greater part of the new plants utilized the vast new hydroelectric potential created in Oregon and Washington, and further expansion made use of natural gas and lignite generated power. The most recent expansion wave is making use of power generated from coal near the mine location. While this may mean slightly increased power costs, there appears to be more than a compensating factor in the reduced distances for transporting aluminum to the consumer from these new plants.

In recent years the U. S. has been mining some 2 million long tons of bauxite within its borders, but bauxite consumption has risen from about 3.8 million tons in 1950 to more than 7 million tons in 1955. The remainder is imported from the Caribbean and northern South America, particularly Surinam and Jamaica.

Reserves in these areas and other South American countries are reportedly adequate for expanding output, and new techniques for using lower quality bauxite and clays may make it possible to expand U.S. alumina production. Experimental use of such material is going on, and it has recently been reported that Anaconda is building a pilot plant for processing clays from northern Idaho into alumina for possible use at its aluminum reduction works in Montana.

It is not anticipated that all of the future aluminum consumed in the U. S. will be produced domestically, for Canada has traditionally supplied the fabricators in this country with considerable quantities of primary aluminum. The U.S. market is presently importing slightly under 200,000 short tons of aluminum from this source.

Until 1941 the U.S. had only one major producer of primary aluminum, the Aluminum Co. of America, but then under the stimulation of rising defense needs and with the help of a loan from the Reconstruction Finance Corp., the Reynolds Metal Co. entered into the field with the operation of the Listerhill, Ala., reduction works. In disposing of aluminum plants built by the government during World War II, the authorities were instructed by statute to foster new and independent enterprises. In this way Kaiser Aluminum & Chemical Corp. entered the field with the aquisition of the Mead, Wash., plant. Anaconda Aluminum Co. became the fourth U.S. primary aluminum producer when its plant at Columbia Falls, Mont., went into operation in 1955.

The Korean emergency again brought defense needs to the fore, and the Federal Government joined with industry in a program calculated to

expand facilities as rapidly as possible for production of more primary aluminum. Even as this emergency faded into the past, domestic uses continued to demand all aluminum diverted away from defense, and the resulting increased production of aluminum from 1952 can be seen on the graph. This continued high level of demand, resulting from expanded usage as well as the substitution of aluminum for ferrous and nonferrous metals and wood, has been the basis for the present tremendous expansion in the industry. In the past few years a number of new plants have been put in operation and a number are now in the construction or planning phases.

The following are the major aluminum expansion projects:

• *Aluminum Co. of America*—This company is building a 150,000 ton aluminum reduction works at Evansville, Ind., scheduled for operation late in 1957. The smelter and a 375,000 kw steam power plant, fired by coal, are being constructed on the Indiana side of the Ohio River, and new docking facilities will handle river shipment of alumina from Mobile, Ala. An 86,000 ton expansion of smelting capacity is also being carried out at Alcoa's Texas and Washington plants which should bring the firm's overall capacity up to an estimated 962,500 tons by 1958.

• *Reynolds Metal Co.*—At Listerhill, Ala., an entirely new aluminum reduction plant of 100,000-ton capacity is being built, and the original plant is being expanded by 20,000 tons. This and several small improvements to capacity of other plants will bring the firm's total capacity up to 575,000 tons by late 1957. Ford Motor Co. is building a die casting plant adjacent to the new Listerhill unit and will transport molten metal in special trucks directly to the foundry.

• *Kaiser Aluminum & Chemical Corp.*—Along the Ohio River at Ravenswood, W. Va., the firm is building an aluminum reduction plant designed to use coal generated power. Initial capacity will be 125,000 tons, but this is expected to be expanded soon to the full capacity of 220,000 tons. Kaiser is also expanding its gas-powered primary plant in Louisiana by another 27,500 tons. Thus, by the end of 1958 the firm's capacity should amount to 682,000 tons. A new alumina plant is to be built at Gramercy, La., and alumina will be brought to the Ravenswood plant by barge along the Ohio River.

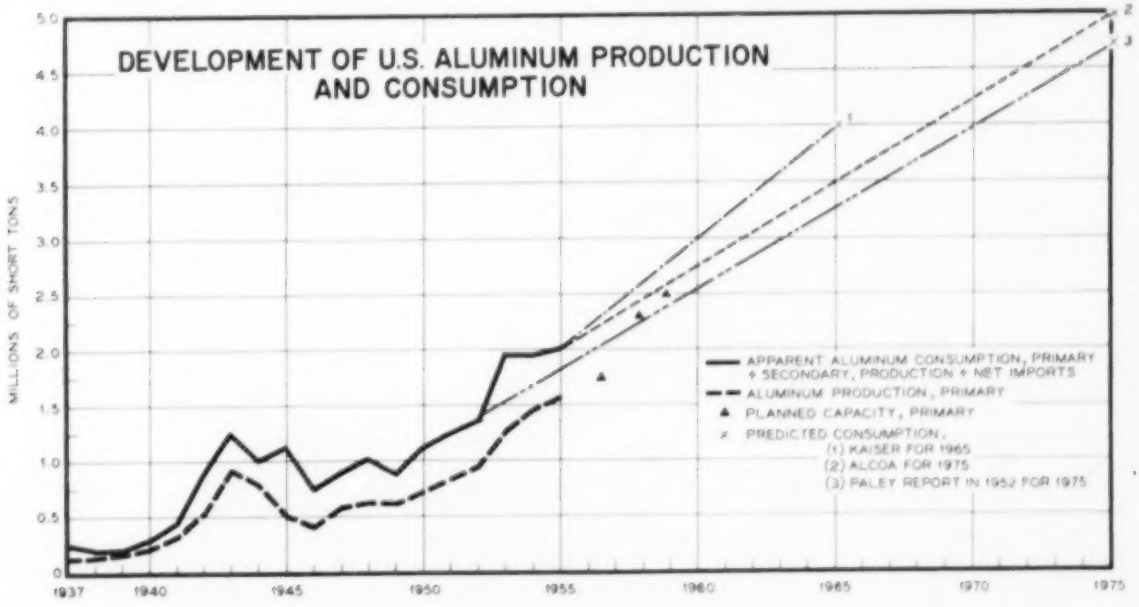
• *Olin Revere Metals Corp.*—This firm, jointly owned by Olin Mathieson Chemical Corp. and Revere Copper & Brass Inc., will be a newcomer to aluminum when its plant, now being constructed at Clarington, Ohio, comes into operation in 1958. Capacity is to be 180,000 tons per year, utilizing coal generated electric power. Bauxite for the operation will be furnished from the Surinam, Dutch Guiana, mines of N.V. Billiton and processed at an alumina plant to be constructed near Burnside, La. Plans call for the transport of alumina to the Ohio works by river barge.

• *Harvey Machine Co.*—It appears that this firm is going ahead with plans to enter into primary aluminum production with the construction of a reduction works at The Dalles, Ore. Initial capacity will be 54,000 tons, and the company plans to increase this by 13,000 tons by late 1958. An interim five-year agreement for alumina supplies has been signed with two Japanese firms, but Harvey later hopes to build an alumina plant. Power is to be supplied by the Bonneville Power Administration.

Certain distinct trends can be noted in this wave of expansion: first, the break in aluminum reduction's dependence upon hydroelectric power; and second, the movement of the industry into the Ohio Valley, close to the metal-working industry and coal deposits, and with low cost transport of alumina available up the Mississippi and Ohio Rivers. One follows the other, and any increase in power costs must be balanced by lower transport costs.

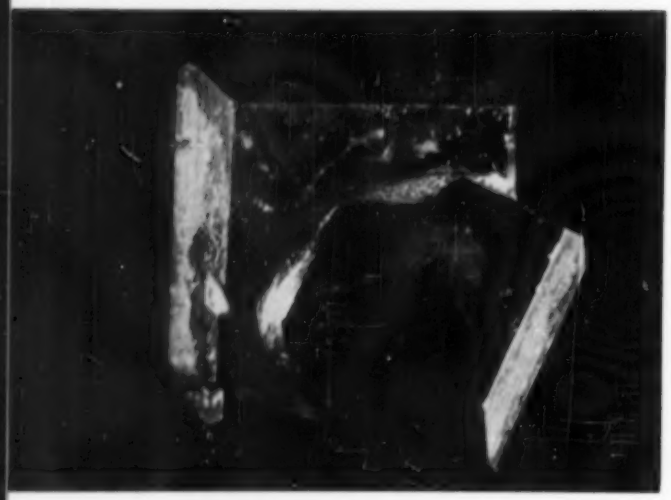
By the end of 1958 these plans should bring U. S. primary aluminum capacity up to more than 2.5 million tons. With secondary production estimated at not less than 300,000 tons, this will put U. S. consumption figure above the most optimistic estimates, even if not a single ton of the metal is imported.

There seems no slackening of demand, and in decades yet to come one may well point to these years as the coming of the *age of light metals*.



Electrolysis Featured in

Gallium Recovery from Bauxite



Translated and Summarized from,
"Etudes sur le gallium"
by Pierre de la Bretèque

GALLIUM, while relatively abundant in the earth's crust, is highly disseminated. Small quantities exist in certain zinc sulfides, germanite, coppery schists (schists cuivreux), some English coals, and especially in minerals containing aluminum. Because of the close chemical similarity between gallium and aluminum, they are generally found together. This similarity, coupled with the fact that gallium occurs only in minute quantities, makes separation difficult. Thus, gallium, known since 1875, is still relatively rare and high in cost.

Properties of gallium have been known for some time, particularly its low point of fusion, 29.75°C, with super cooling to temperatures below 0°C; its high boiling point, about 2000°C; its considerable expansion on solidification; and its anisotropy, which is much greater than that of other metals.

During the production of alumina from bauxite by the Bayer process, gallium, along with aluminum, is dissolved by caustic soda. The recycling of caustic solutions in the process results in an enrichment of gallium to a critical concentration. Beyond this point compounds of the metal are deposited along with the hydrate of alumina. Thus, in an equilibrium operation, the same quantity of gallium enters the treatment plant in bauxite as leaves the plant in alumina.

PIERRE DE LA BRETÈQUE is chemist at an alumina plant associated with the Swiss AIAG, Aluminium-Industrie-Aktien-Gesellschaft, whose Research Laboratories at Neuhausen am Rheinfall, Switzerland, have actively encouraged this work. The book was originally prepared as a doctoral dissertation at the Université d'Aix-Marseille, France.

The extraction of gallium from these caustic solutions has been the object of much research work, and there are now a number of recovery methods. All have the effect of more or less altering the character of caustic solutions, rendering their reuse difficult. Since the economics of the Bayer alumina process depend, to some extent, on the recirculation of caustic solutions, gallium extraction has been a costly venture. The research work undertaken by the author had as its object extraction of gallium from caustic solutions under conditions which prevent modification of the solutions.

After the precipitation of alumina hydrate, the caustic solutions, while poor in aluminum, still have a relatively high gallium concentration (for example, 0.20 gpl). This would appear to be the opportune moment for gallium removal. Chemical extraction does not seem feasible, for, in these highly alkaline solutions, constituents other than gallium enter actively into the reactions.

The author was, thus, directed toward physicochemical separation techniques. Several methods were investigated, but only one appeared practical on an industrial scale. The direct electrolytic deposition of gallium was considered; however, the experience of others was discouraging. Solutions containing both sodium aluminate and gallate can not be completely stripped of gallium, but it did appear possible to deposit directly at least some gallium. The author, therefore, decided to examine closely the conditions most favorable to the electrolytic deposition of gallium.

Experiments were first conducted on artificially prepared solutions of exact composition, similar to the industrial bauxite leach solutions. At the cathode there was a simultaneous discharge of hydrogen and deposition of gallium, and experiments were conducted with cathodes of a metal of high hydrogen adsorption. Lead was first used, but corrosive action prevented its adoption, and attention was turned toward mercury. The first experiments were conducted with a voltage low enough to prevent an apparent release of gas, but these resulted in only a trace of gallium being deposited. Later work was conducted with higher voltages and current densities. Experiments were carried through in detail to ascertain effects of time, temperature, agitation, voltage, and current density on the deposition of gallium.

Experimental Results

These experiments established a process for the extraction of gallium from aluminate leaches in the course of production of alumina from bauxite. The process permits the separation of rich vanadium compounds, as well as the elimination of certain impurities in the caustic solutions.

The leach of sodium aluminate, containing compounds of gallium in solution, is submitted to electrolysis preferably after deposition of alumina hy-

drate. The following are the conditions of the electrolytic cell:

Cathode—mercury **Anode**—nickel

Temperature—40° to 50°C

Current Density and Terminal Voltage—At the cathode, the current density is 0.45 amps per sq dm or slightly lower, provided the potential of the cathode is not lower than 1.9 v (compared with a hydrogen electrode). At the anode, current density is from 20 to 60 amp per sq dm, in such a manner as to have the terminal voltage a minimum of 3.8 v.

Agitation—For the best operation, agitation of the liquid and the surface of the mercury should be as strong as possible without causing the separation of balls of mercury from the surface of the cathode. This is achieved by immersing a horizontal rectilinear agitator from 2 to 3 mm in the mercury. The container is cylindrical, and the agitator sweeps the entire surface of the cathode. For a container diameter of 16 cm, the speed of the agitators is two turns per sec.

Cathode Deposit—Gallium deposited on the mercury cathode rapidly diffuses under the effect of agitation. This removal of gallium from the surface of the cathode permits, through depolarization, the deposition of further amounts of gallium. In this manner from 0.4 to 0.5 g of gallium are deposited per sq dm of cathode in 24 hr. This requires about 100 whr or 25 amp-hr at 4 v per g deposited.

A variable quantity of sodium is also deposited on the cathode, but such deposition may be minimized with high temperatures, low current densities, and strong agitation. Also, with the gallium being accumulated in the mercury and the same cathode being made to serve for successive electrolyses, the sodium rapidly ceases to accumulate. In general sodium is found in the mercury to an extent not greater than one part per thousand.

Cathode Treatment—The mercury cathode, after washing in water, is treated with caustic soda in the presence of small pieces of iron. This iron, together with the mercury and the solution, constitutes a galvanic cell at a temperature near boiling. Gallium is taken into solution as sodium gallate, the mercury is separated from the aqueous solution, and gallium is recovered by a second electrolysis.

Gallium Refining—In a second electrolysis, the electrolyte, containing from 60 to 80 gpl of gallium, is treated in a cell with a cathode of inoxidizable metal (or gallium itself) and an anode of nickel. The anode current density is 3 amp per sq dm, while the cathode current density is 150 amp per sq dm. Terminal voltage is from 5 to 6 v, the temperature is maintained at 70°C, and there is weak agitation. Some 95 pct of the gallium in solution can be extracted with a current efficiency from 40 to 50 pct. For this second electrolysis some 20 to 25 whr per g of gallium deposited is required.

A quantity of silicon, varying between a tenth and a twentieth of that of gallium, is deposited on the cathode in the primary electrolysis. This silicon is also redissolved in caustic soda and carried to the second electrolytic cell. Its presence does not materially affect operation of the second cell, but build-up of silicon concentration does prevent reuse of the caustic electrolyte from the refining cell.

Vanadium Removal—The leaching solution, from which gallium has been extracted, has changed in appearance from clear and reddish yellow to turbid and dark brown. By decantation or filtration, the original color of the caustic leach is restored, and a dark brown precipitate is removed. This precipitate, analyzing about 30 pct V, contains all the vanadium initially in the leach.

In the course of electrolysis, pentavalent vanadium is reduced to the tetravalent state and tends to precipitate, probably as the hydrate of V_2O_4, prior to the deposition of gallium. This does not appear to influence extraction of gallium, for this vanadium reduction is a chemical reaction utilizing hydrogen already discharged from the cathode.

In the Bayer process as presently practiced, part of the vanadium is recovered from the leach solutions as they become super-saturated in sodium vanadate. The high vanadium content of the recirculated leaching solutions prevents their dissolving appreciable quantities of vanadium from the bauxite. With this new process, however, vanadium is completely removed from the leaching solutions, which are then capable of dissolving the majority of vanadium compounds in the bauxite ore.

Conclusions

The overall effect of this process is not only to recover valuable byproducts from the leaching solutions of the Bayer alumina process, but also to purify the recycled caustic leaches. Certain other impurities, notably iron, are also removed.

In the course of a series of 24 trials, the operating results shown in Table I were obtained, and the process is now undergoing further investigation at a pilot plant operating at one of the alumina plants of the Aluminium-Industrie-Aktien-Gesellschaft.

Table I. Results of a Series of 24 Tests of Electrolytic Gallium Extraction Technique

	Maximum	Minimum
Current efficiency, pct	5.7	5.0
Energy consumed, whr per g	88.5	76.5
Gallium deposited in 24 hr per sq dm of cathode, g	0.536	0.464
Gallium content of untreated solution, gpl	0.179	
Gallium content of treated solution, gpl	0.054	

In order to give some idea of the results which can be expected from this process, assuming the efficiency of gallium attack in the digestors to be about 90 pct, the following are the operating results obtained in 24 hr:

Reference Tonnage of Bauxite Treated, at 0.007 pct Ga		10 metric tons
Gallium produced		600 g
Volume of Leach Treated, at 0.18 gpl Ga and 0.5 gpl V_2O_5		4.8 cu m
Electrolysis Tank	Cathode	12 sq m
	Mercury	about 1 metric ton
Energy Consumed		60 kw-hr
Vanadium deposited (in V_2O_5)		about 2.5 kg

While M. de la Bretèque operated with a cathode current density of 0.45 amps per sq dm, using an initial aluminum:gallium ratio of 160 to 170, and finding no interference from the presence of organic material, three Hungarians,[1] recently obtained different results. For satisfactory electrolysis they recommend a current density of 0.8 amps per sq cm, an aluminum:gallium ratio below 100 with a minimum gallium content of 10 mg per liter, and the elimination of organic material.

[1] E. Papp, A. Hejja, and J. Oevges: *Extraction du gallium metallique des bauxites hongroises* (in French), Acta Technica Scientiarum Hungaricae, 1956, vol. 14, No. 1-2, pp. 55-76.

at Union Carbide

There is New

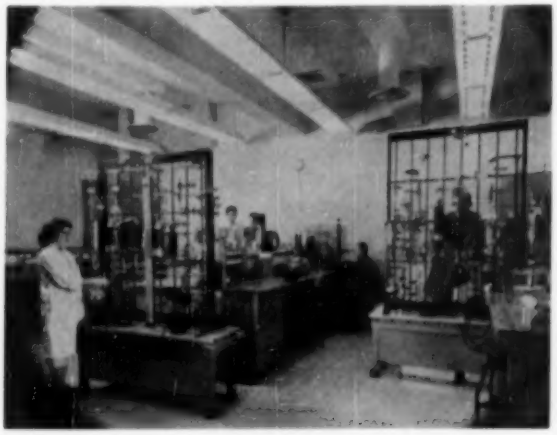
WITH industrial processes traveling at ever faster speeds toward the brink of present knowledge, many of the large industrial concerns of America are turning a more conscious eye on technological research. Last month on the outskirts of Cleveland, at Parma, Ohio, National Carbon Co., Div. of Union Carbide and Carbon Corp., opened an ultramodern research laboratory. Work will center in the fields of solid state physics, electrochemistry, carbon and graphite research, and high-temperature refractory compounds. Nothing has been spared to completely equip the laboratory for research in these fields.

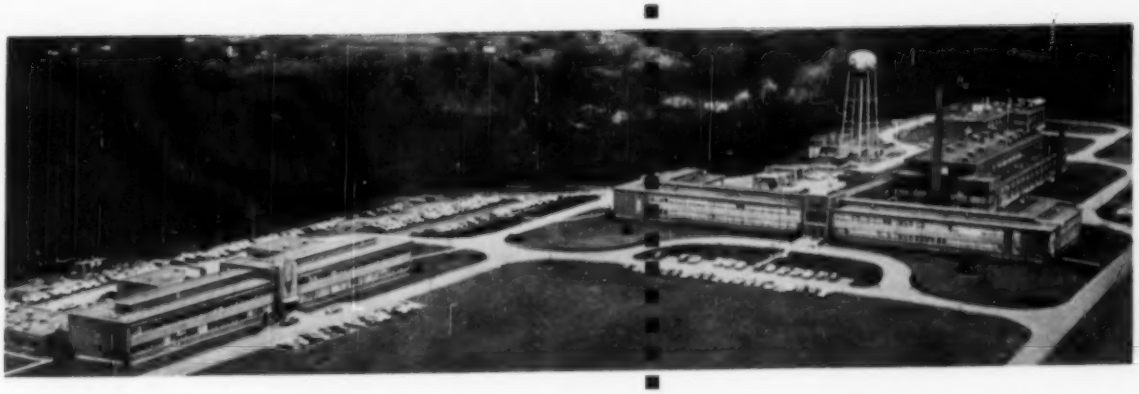
A field emission microscope is being used to provide a means of photographing electrons that flow from the surface of a metal subjected to an electric field. Characteristic patterns reveal surface details of metal specimens as part of basic research on chemical reactions at catalyst surfaces. Previously unknown realms of science will be investigated with this new *crystal ball*.

Fuel cells, demonstrated at left, are batterylike devices that obtain electricity directly from gases, such as oxygen and hydrogen, which serve as the positive and negative poles. Carbon elements that will withstand high currents for long periods are the aim of fuel-cell research at Parma.

Other work at the laboratory concerns the triple point for carbon —National Carbon scientists have succeeded in welding pieces of graphite together, boding new and radical fabricating techniques with wide applications. A high altitude chamber capable of simulating conditions at 150,000 ft is used to determine special properties of carbon for aircraft applications.

Typical of some 158 similar units at the new lab, the research module shown below is equipped with a wide variety of voltages and gases to meet every research requirement. Rare gases can be piped in when needed. Movable metal partitions make it possible to rearrange individual modules as required.





. . . . and at U.S. Steel

Emphasis On Research

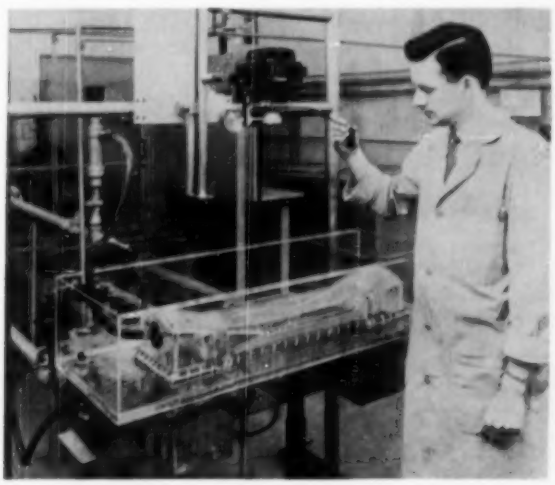
MONROEVILLE, Pa. is the location for U. S. Steel Corp.'s new research center. Fifteen miles due east of Pittsburgh, the center consists of two separate laboratories—the Applied Research Laboratory and the Edgar C. Bain Laboratory for Fundamental Research.

In the new center, scientists are studying problems ranging from the development of new alloys to withstand the high temperatures of jet engines to chemicals derived from coal. Small-scale steel melting furnaces, rolling mills and coke ovens are among the many pieces of research equipment which will be in operation.

Plastic blast furnace models like the one shown at right are used for investigating the flow of solids and gases in the furnace. The technician is shown checking tuyere pressure as granulated coke flows through the model.

Coke is shown being pushed from one of the four experimental coke ovens in the lower right picture. Different types and combinations of coking coals are tested to determine the most satisfactory blends.

The bottom picture shows a plastic model of a modern open hearth, using water to simulate the flow of gases through the furnace.



. . . and at Westinghouse!

COMING to our offices just in time to make publication deadline was news that Westinghouse Electric Corp. has just opened its new laboratory in Churchill Borough, about 10 miles east of Pittsburgh. Work will be conducted in eleven fields, including magnetic and semiconductor solid state physics, electronics and nuclear physics, metallurgy, and technology. Facilities are available for producing extremes in pressure and temperature along with appropriate devices for accurate measurement.

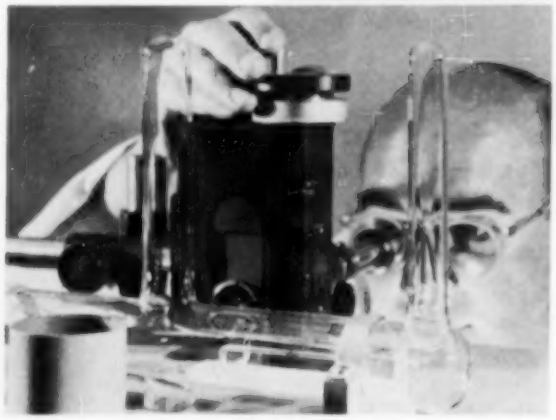
Superconductivity is one of the riddles of modern physics that is under consideration. High frequency microwaves are being used in this investigation—frequencies of 200 billion vibrations per second are not uncommon.

Heated to a temperature of 4000°F in the airless glass chamber shown at left, an experimental alloy is being treated in a near perfect vacuum—giving valuable knowledge that will lead to better alloys for high temperature service.

Inside the tanklike furnace shown at right, steam at 1200°F under a pressure of 16,000 psi is being used to test the strength of the stainless steel casing. Its ultimate use will be in a new type steam turbine for electric power generation.

The library of the new lab is shown at the bottom left. Housing some 30,000 volumes, the library also subscribes to some 550 periodicals from all over the world.

Capable of weighing one layer of oxygen atoms on a tiny metal sample, the quartz-bar microbalance shown in the bottom right picture registers weights of one-hundred-millionth of an ounce.



As The Demand For Engineers and Scientists Rises

Business Learns of

The High Cost Of Thinking

by J. J. Burke

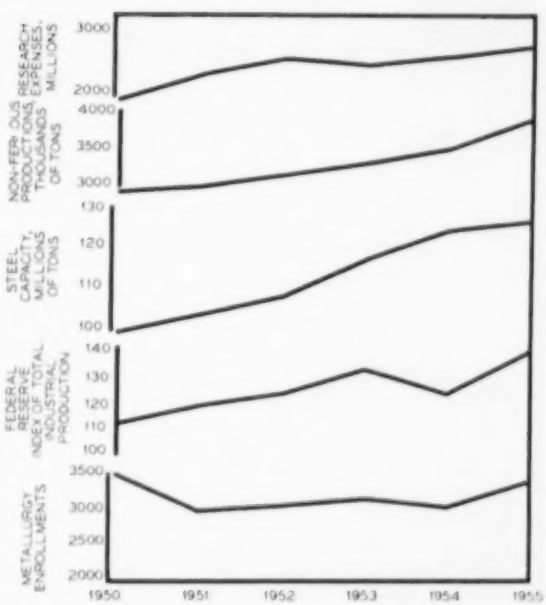
Bethlehem, Pa., Sept. 3—Seniors aren't back on the Lehigh University campus for their final year of study, but the scramble for 1957 college graduates is on. That was the report this morning. . . .

—News Release

AND that is the report this morning at every engineering school across the country. Why is this? Is the problem simply one of supply and demand? Or are the factors involved too complex to be stated so simply? These are some of the questions that have cropped up under the recent barrage of publicity about the shortage of "our most vital resource." The problem is stated graphically at the right. However, it is not the job of leading educators, industrialists, and Presidents' Committees to put the answers into effect. It is the job of every professional engineer and scientist. The shifting of emphasis in our society toward more planned research and development has brightened the professional status of the engineer and scientist, but this change has been largely ignored. It is necessary that management recognize its dependence on technical achievement and be ready to reward that achievement both monetarily and by accepting the men responsible as part of the management team.

It must be emphasized that in the rush for quantity, we must not lose sight of quality. If the profession is to advance, the standards of quality of its members must be held at a high level. With sufficiently high academic entrance requirements to colleges and universities, and adequate screening techniques, we may eliminate those who are unsuited for this field.

Perhaps the most important short range point for industry is utilization, or *brain conservation*. Several companies—notably I.B.M., General Electric, and Westinghouse—have literally increased their engineering staff 10 or 15 pct by the simple expedient of handing non-technical and routine jobs over to technicians and assistants.



Enrollments in metallurgy, compared to several other parameters, are shown above. Nonferrous production is for tonnage metals only (copper, lead, zinc, and aluminum), and does not show the tremendous interest in the newer metals —uranium, titanium, zirconium, and hafnium. The Federal Reserve Index of Total Industrial Production is closely allied to steel production and does not reflect the fantastic expansion in fields like aluminum.

Science Education: Dying Out?

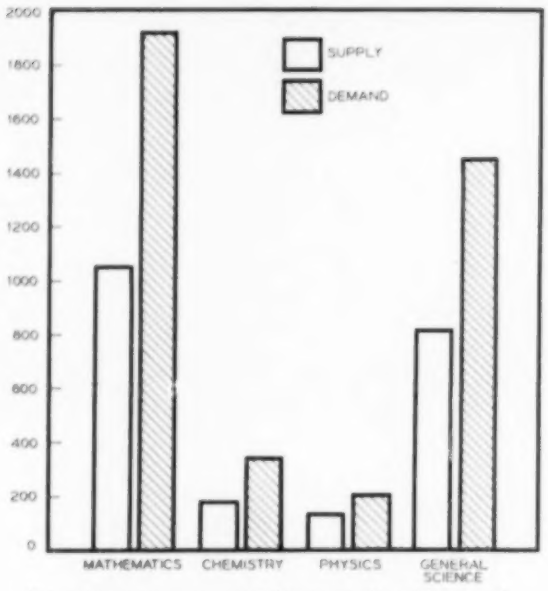
By far the toughest facet of the problem is that of encouraging students into engineering and science. The problem divides into two categories, both of them formidable: 1) The teaching of science and mathematics is in critical condition; and 2) Less than half of the qualified high school graduates ever enter college.

The teacher shortage is illustrated on the following page, but it only tells part of the story. One discouraging fact is that, of the teachers certificated between September 1954 and August 1955, only 50 to 60 pct were in the classrooms in November 1955, due to more lucrative offers from other fields. Another cause for concern is that the number of graduating teachers of science and mathematics has dropped about 50 pct below the 1950 level. A correlation between these figures and future college enrollments in science and engineering is not pleasant to contemplate.

Mr. C. E. Weed, President of The Anaconda Co., recently emphasized the importance of catching potential engineers at an early age: "Engineering is a difficult course of study, more difficult than law; if a student does not cultivate an interest in science and mathematics during the early part of his secondary schooling, he will simply not be able to select engineering when he goes to college." Mr. Weed also stated that, while it is difficult for the metals industry directly to influence secondary school teaching on a nation-wide basis, it is their responsibility as private citizens to do whatever is possible to encourage proper teaching of science and mathematics in their own communities.

The subject of "Why Johnny Can't Add and Subtract" was explored recently by the Educational Testing Service, and the results are gloomy indeed.

The teachers themselves are in many cases unqualified, and a large number admitted *hating* mathematics. Mr. Samuel Schenberg, Supervisor of Science for the New York City Board of Education, recently stated that the two points of major importance are low salaries and low morale. It is the sort of problem where curing one ill will remedy the other. Once teachers get the recognition they deserve, the salary boosts, which they also deserve, will be forthcoming. Educators desire to make two years of science and three of mathematics mandatory for all students taking college preparatory work. However, Mr. Schenberg frankly admitted that teachers were not available to implement any such program. Present day college graduates were born in the thirties—years of an abnormally low birth rate. The war-time boom in babies, already a serious problem in the primary and secondary schools, will soon be thrust upon the colleges, and science and engineering should get their share. However, it will be of little avail if the students are not prepared to handle college level work in mathematics and science.



Shown above are some recent figures on the existing supply and demand of teachers in critical fields.

On the Job Ahead

By Dr. Albert Watson Davison, *Chairman of the Engineers Joint Council of the Engineering Manpower Commission, who is consultant at the Owens-Corning Fiberglas Corp.*

For the past eight years engineers and scientists, industrialists, educators, and officials of the armed services and of government have realized that American leadership in science and engineering has been challenged by the Soviets. While much has been done toward calling the attention of our people to the seriousness of this situation, and much has been done toward correcting the inadequacy of the numbers of men and women trained along these lines, a great deal yet remains to be done in encouraging qualified young people to enter careers in science and engineering. Young women are needed, because there are excellent opportunities for members of their sex in teaching, and qualified teachers of mathematics and science are required if we are to educate the scientists and engineers we will need in the future.

We should not lose sight of the fact that it takes at least ten years to train a boy or girl in the high school, the technical school and in industry before he or she begins to become effective. For the long pull, industry and government must do a great deal more than they have in the past in the way of encouraging our young people to enter careers in science and engineering, in bolstering up the caliber of secondary school education in mathematics and science, and in seeing to it that capable men and women are retained as teachers both in the secondary school and in the technological institutes.

The national seriousness of the shortage of engineers and scientists is attested by the activities of the President's Committee for the Training of Scientists and Engineers. But this committee, while it is composed of the nation's best minds, cannot do the job unless laymen, engineers, scientists, and industrialists back them up by inducing more of our most capable young people to enter technological careers.

In the field of metallurgy there is an active group concerning itself with the problem of getting more students interested in the subject. It is called the Special Committee on Manpower for the Metallurgy and Ceramics Professions, and is sponsored by AIME, ASM, and the American Ceramic Society, with General Electric paying the bills. They have embarked on an *Awareness* program, the goal of which is to make people more aware of the attractions and challenges of the field. This is being aimed toward high school seniors, junior high school students, and, since it has been shown that students are swayed heavily in their career choice by their parents, toward the public at large. The committee is reviewing all scholarships in the field with a view toward recommending additional industrial support of the type noted below.

Notable gains have been made by industry in the realm of scholarships and aid to institutions; an excellent example is the $1,000,000 grant recently made by the International Nickel Co. Of the 57 scholarships that this grant will support, 47 were specified for science and engineering, with the emphasis to be placed on mining, geology, and metallurgy. More and more companies are learning that this practice is good business, but what has been done so far is only a beginning.

The Experienced Engineer: Answer to His Own Problem?

Although the pay check of the recent graduate has gone way up, there has been no corresponding raise for men with several years experience. The rise in starting salaries has narrowed the gap between bottom and top in every technical field, and many experienced engineers find themselves getting little more than members of the skilled trades. One answer that this type of person has

On Educating The Uncommon Man

By Dr. Edwin S. Burdell, *President, The Cooper Union For The Advancement of Science and Art, a school which will soon celebrate its 100th anniversary of teaching talented students on a tuition-free basis.*

My theme is taken not from an educator, but from an industrialist—C. H. Greenewalt, president of the DuPont Co. These words are worth repeating:

"I know of no problem so pressing, of no issue so vital. For unless we can guarantee the encouragement and fruitfulness of the uncommon man, the future will lose for all men its virtue, its brightness, and its promise."

Our American democracy has fought shy of elite groups, whether by birth, wealth, or brains. We have promoted an egalitarianism which runs the risk of defeating our efforts to meet our more pressing needs. Our teachers are paid less than our factory workers and their station in life is rated not much above the common soldier and salesman. Occasional waves of anti-intellectualism threaten to stifle the exploration of the unknown, whether physical or social. Be this as it may, the development of the potential brain power of intellectually superior men and women is our greatest need. Unless we are willing to run the risk of educating a few intellectual misfits beyond their capacity of assimilation, we will never succeed in increasing the supply of indispensable men and women, the uncommon men and women.

If we would increase the nation's utilization of its potential brain power, we must start early, use all the resources at our command, and use them with increasing imagination and vigor. This should be initiated when the pupil is of secondary school age, at the most; and perhaps it can be achieved through a comprehensive approach that will utilize not only an improved educational program in the high schools, but also the manifold educational influences that exist in the community. Industrial leaders, scientists, designers, and professional men who have a capacity for colorful direct speech would be valuable as speakers to high school students who are at the stage of considering college and career. "As the twig is bent, so is the tree inclined," is an old adage worth bearing in mind here.

Good teaching, successful student performance, and a high motivation usually are found together, and it is impossible to say which are the causes and which are the results. The uncommon pupil will flourish in any situation where these factors are present, but will not be likely to discover his talents in an atmosphere of avoidance and distaste for mathematics, the basic language of science. On the college level, the kinds of curriculums and courses designed for the average student may put the uncommon student in a mental straitjacket, may restrict the full play of his intellectual and creative powers. The talented student responds joyfully to an academic atmosphere of freedom and accent on self-reliance and resourcefulness.

That "capacity for fundamental originality," which good teaching can help to instill in the gifted mind, is the essence of creativity—of the creativity that Sir Herbert Read called the only adequate compensation for the conformity and the suppression of individuality which community life requires today. It is a requisite for the uncommon teacher, if the teacher is to help his students become uncommon men and women.

found is job-hopping. A recently published attitude† on this subject runs like this: "You're a sucker if you've been on a job for more than a year and are not actively shopping around for more money. Only by this technique can you advance your salary and keep ahead, percentage-wise, with starting rates for engineers and comparable industry increases in other non-engineering fields." It goes without saying that this attitude is not in the best economic interest of the companies involved. Yet, where does the blame lie?

Some companies that advertise widely for scientific talent are interested only in those who do not state a minimum salary requirement. They are, in reality, looking for low priced talent. Companies that pay their professional employees adequately and raise those salaries commensurate with their starting pay are, in many instances, barely aware that there is a shortage of engineers. Supply and demand is still working.

To discourage this job-hopping, it is reported that several large companies have agreed not to *raid* one another of technical talent. This highly unethical practice is just as surely in restraint of trade as any monopoly. It is of utmost importance that the freedom of the individual to find the best paying job be rigidly maintained, for it is in this way that supply and demand take their natural course. As is noted elsewhere, the practice of raiding the schools and colleges of teachers is one which contributes mightily to the present shortage of these important people. Yet, if these teachers were offered adequate compensation in their profession, they wouldn't even consider leaving it.

As Hamlet said, *The time is out of joint.* Present policies for paying both engineers and teachers are definitely out of joint with the times, and are, in short, an anachronism. A recent article in a trade magazine was entitled "New Partnership—Business and Education."* All of the fine old phrases—democracy, free enterprise, capitalism and more—are based on the successful functioning of business and education. Let us hope that both, in their new partnership, will recognize the importance of their most valuable assets. As supporting members of both institutions, this is up to you.

† *Northwest Professional Engineer*, September, 1956.
* *The Iron Age*, September 6, 1956

New Developments In

Smoke Control at Cominco

by R. Bainbridge

IN most smelting operations, one of the principal tonnage materials entering the reaction is air. For example, in the smelting of lead at Cominco, it takes about 550 tons of air to dry the sinter plant charge, 1000 tons for sintering, and 400 tons for blast furnace operation to produce 100 tons of bullion. Removal of such impurities as antimony and arsenic in the refining of silver is also dependent on the proper use of air.

The bulk of this process air is converted to a hot, frequently corrosive, gas mixture carrying metal values. This metal is in the form of mechanically picked up dust, or fume produced by volatilization of metals or metal compounds. For reasons of economics it is required that these metal values be recovered. Also, to maintain safe standards of industrial hygiene, the discharge of contaminated gas directly to the atmosphere should be minimized.

The characteristics of the gas to be treated determine, to a large degree, the type of equipment which should be used to collect and recover dust and fume. Usually this equipment will be one of the following: a) electrostatic precipitation unit, b) baghouse, c) wet scrubber. In Cominco's lead smelting and refining departments all three types are utilized.

Satisfactory operation of an electrostatic precipitator or a baghouse requires that the gas, along with entrained dust and fume, be prepared properly for subsequent dust removal. This preparation may be a *conditioning*, that is, making a dust and fume, which may have high electric resistivity at the operating temperature, and be sufficiently conductive for electrostatic precipitation; or cooling, as in the case of a baghouse. For wet collection in a scrubber, such factors as the degree of efficiency required, average particle size of the dust and its resistance to wetting, and the presence of corrosive elements will influence design requirements. Considerable development work has been undertaken during the past few years to improve techniques involved in collecting dust and fume by each of the above methods, and these developments are discussed below. Although based on the metallurgy of lead, it should be applicable to many industries where the recovery of dust or fume is a problem.

R. BAINBRIDGE is Asst. Supt., Development, Smelting, and Refining, Metallurgical Div., Consolidated Mining and Smelting Co. of Canada Ltd. This article is based on a paper presented at the New York Meeting, February 1956.

Gas Conditioning for Dust Recovery by Electrostatic Precipitation

Proper conditioning of gas and dust is of utmost importance for efficient operation of a dry-type precipitator. Lead-bearing dust and fume produced in sintering is nonconductive. Operating experience and the findings of other investigators show that collecting efficiency varies with the electrical conductivity of dust and moisture content of the gas. It is reported that resistivity of a dry sintering plant dust will reach an extremely high peak at about 275°F, whereas at 100° or 400°F the resistivity is much lower. However, as the moisture content of the gas increases, the peak resistivity is lowered, as shown in Fig. 1. The reasons for this are twofold. The layer of dust built up on the collecting electrode, if nonconductive, develops an electrical potential, and sparking occurs between the electrodes; also, dry, nonconductive dust constitutes a porous dielectric which, in effect, simulates a *point to point* electrical stress between electrodes. The result of this effect is to reduce the voltage that can be maintained between electrodes. As dust particles adsorb water, they become conductive and operating difficulties decrease.

Also, moisture in the gas has a direct effect on the corona discharge and the sparking voltage between a point and plate. Sparking potential is a function of the moisture content of the gas.

In the Cominco sintering operation, gas leaves the machines between 250° and 350°F. It is in this

range that the dust is least conductive, and conditioning by water adsorption is necessary. Gas velocity in the existing flue and humidification chamber is low, and it has been found necessary to introduce an excess of spray water to moisten the dust sufficiently for reasonable treater efficiency. Not only has control of such factors as moisture content of the dust and relative humidity of the gas been difficult—Fig. 2—and contributed to corrosion, but also the run-off of excess spray water creates a slime recovery problem.

With these operating problems in mind, test equipment was designed on the premise that good conditioning is dependent on the impingement of droplets of water on dust particles at a velocity sufficiently high to overcome surface tension. It was reasoned that, if dry gas were injected at high velocity into the top of a tower where it was allowed to expand suddenly, turbulent flow would result, and if a well atomized, high pressure water spray were admitted co-axially with the gas, the probability of impingement would be increased.

A 5-ft diam by 17-ft high steel tower was built to investigate conditioning of blast furnace and sintering plant gas. By means of a fan, gas was drawn centrally into the top of the tower through a relatively high velocity jet—65 to 85 ft per sec—and 300 psi water was introduced into the gas stream through standard Meyers sprays. To determine the degree of dust and gas conditioning, a gas sample was drawn from the tower outlet and passed through a single pipe test treater. In general, it was demonstrated that the dust was adequately conditioned for efficient treater operation. For the arrangement of equipment and essential data, see Fig. 3 and Table I.

In order to determine additional data, particularly the effect of inlet gas velocity, velocity through the tower, and relative humidity of the outlet gas, another series of tests was run on sintering plant gas.

It became obvious from the latter series that conditioning was most effective when the moisture content of the gas approached saturation. This verified previous experience, but introduced an operating problem. If, in the gas at the humidifying tower outlet, saturation were approached, water would be released from the gas stream during passage through the precipitator units due to cooling. To overcome this, a portion of the hot gas was made to bypass the humidification section, and this was sufficient to raise the temperature of the conditioned gas so that it would not subsequently cool below the dew point.

It is to be noted that in these tests, the degree of conditioning was indicated by the relative distance of a high voltage discharge between a point and plate with and without test dust on the plate. The equipment used is shown in Fig. 4.

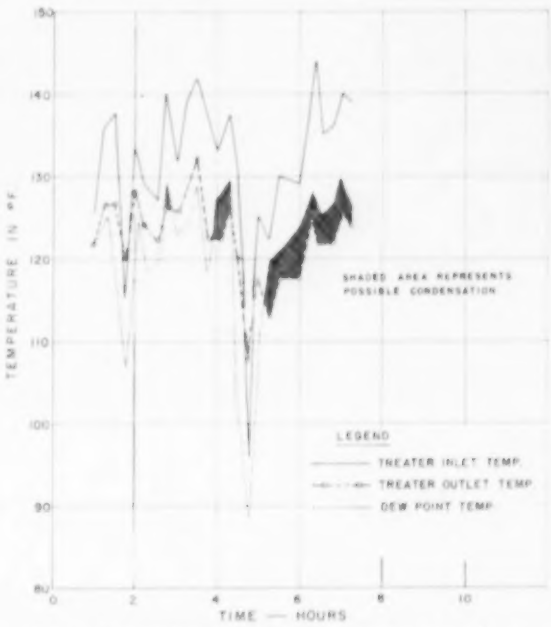


Fig. 2—Temperature relationship in a treater unit with inadequate control of spray water.

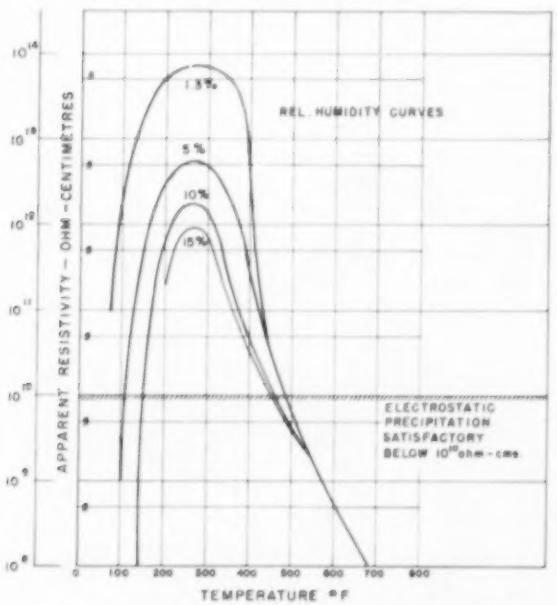


Fig. 1—Apparent resistivity of lead fume from a sintering plant (with permission, *Industrial and Engineering Chemistry*).

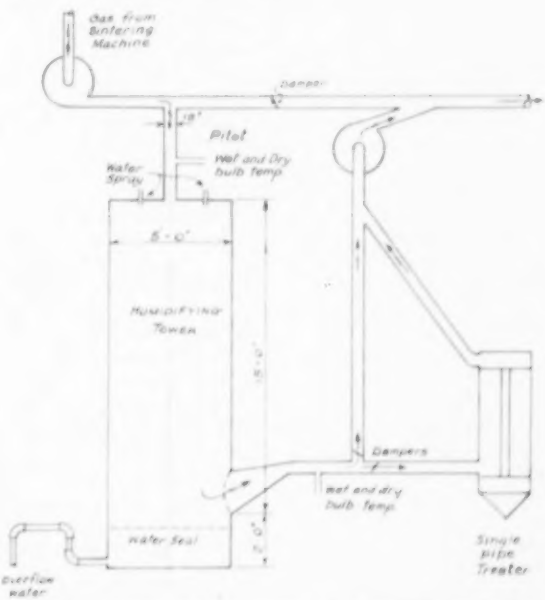


Fig. 3—Experimental arrangement of the humidifying tower and treater.

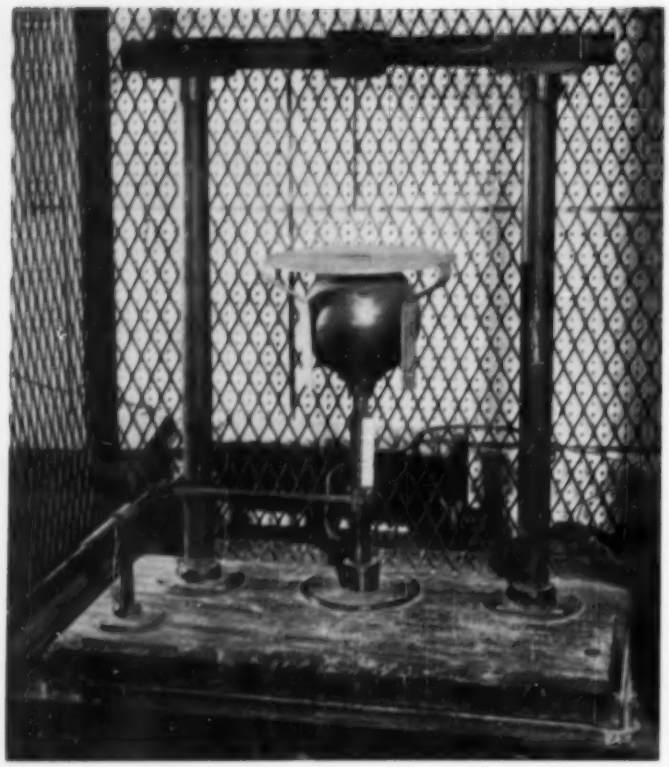


Fig. 4—Left—View of spark-gap equipment used to determine relative conductivity of metallurgical dust and fume.

Fig. 5—Right—Cooling equipment. At top is the tube cooler for gas from the silver refinery furnaces. At the bottom is the cooling tower installation for treating the same gas. Framework of the original tube cooler is shown in background.

Using the test data as a guide, a new flue and humidifying tower are now being designed to handle and condition an average of 10,000 lb per min of sinter plant gas containing about 3 pct SO_2. This new system will be designed to: 1) maintain a normal flue velocity of 50 to 60 fps to hold dust fallout to a minimum; 2) condition the gas by addition of water automatically controlled to approach 100 pct relative humidity; 3) automatically regulate the volume of hot gas which will by-pass humidification to control the relationship between wet and dry bulb temperatures at the treater inlet; 4) automatically control draft conditions throughout the system; and 5) minimize corrosion, construction being of lead-clad steel wherever possible.

Gas Cooling For Baghouse Operation

Cooling of metallurgical gas is essential for most operations where dust is recovered by filtering in a baghouse. Such factors as gas volume, temperature, and dust concentration, will determine the method or methods employed. For example, for a slag fuming operation, where there is a large volume of gas at a relatively high and constant temperature (2100° to 2200°F), the bulk of the heat can be removed in a waste heat boiler. The remainder of the cooling can then be done by evaporation of automatically controlled water spray and by tempering air.

For lead blast furnace gas, where volume is high and temperatures can vary rapidly over a wide range, cooling may be effected by water spray and tempering air. Details of such a design at Cominco were outlined in a paper published in the December 1952 JOURNAL OF METALS. For smaller volumes of gas, other types of cooling equipment are frequently used. A common installation is the *trombone* type pipe cooler. This type of cooler has a low heat transfer rate, and if gas is corrosive, it is subject to heavy maintenance costs. Plant development has resulted in a new cooling tower arrangement, shown in Fig. 5, which is subject to accurate control and requires little maintenance.

Original work on the development of a tower for gas cooling was based on results and observations made during gas humidification tests. It was noted that when the volume of the gas through the tower was allowed to increase, the heat loss was greater than had been expected. Operating figures were checked, and the rate of heat transfer was calculated and found to be as high as 6 Btu per sq ft per hr per °F difference, as compared to less than 1 Btu for an existing trombone tube installation. Cooling data for this latter installation are recorded in Table II.

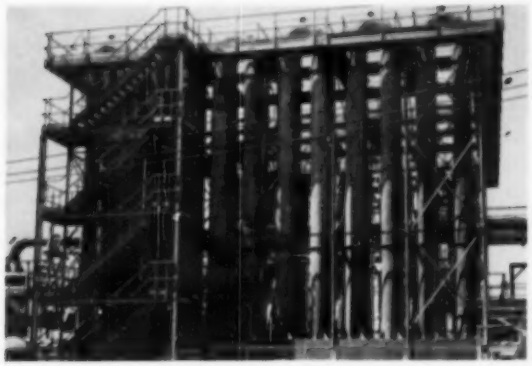
For high gas volumes, a constant 10,000 cfm, the following data are typical:

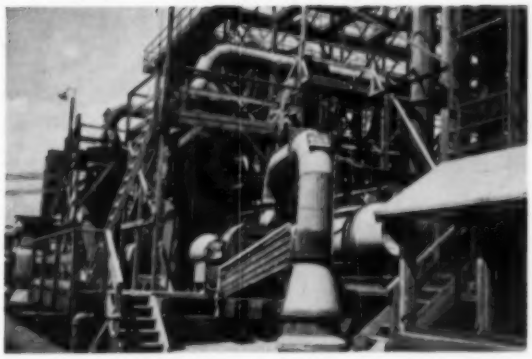
Tower inlet temperature, 400°F
Tower outlet temperature, 308°F
Atmospheric temperature, 60°F
Surface area of tower, 286 sq ft
Surface area of piping, 20 sq ft
Sp ht of gas, $0.0188 + 1.37 \times 10^{-6}t$
Gas volume, 10,000 cfm
Q (in) $= 5410\ (0.0188 + 1.37 \times 10^{-6} \times 400)\ 400 = 7.7392 \times 5410$
Q (out) $= 5410\ (0.0188 + 1.37 \times 10^{-6} \times 308)\ 308 = 5.9204 \times 5410$
Q (in) $- Q$ out $=$ heat transferred per min $= 1.8188 \times 5410$
$= 9840$ Btu per min
Btu per min

Log mean temperature difference

$$= \frac{(400 - 60) - (308 - 60)}{\log_e \frac{400 - 60}{308 - 60}} = 291°F$$

$$U = \frac{9840 \times 60}{306 \times 291} = 6.62 \text{ Btu per hr per sq ft per °F}$$





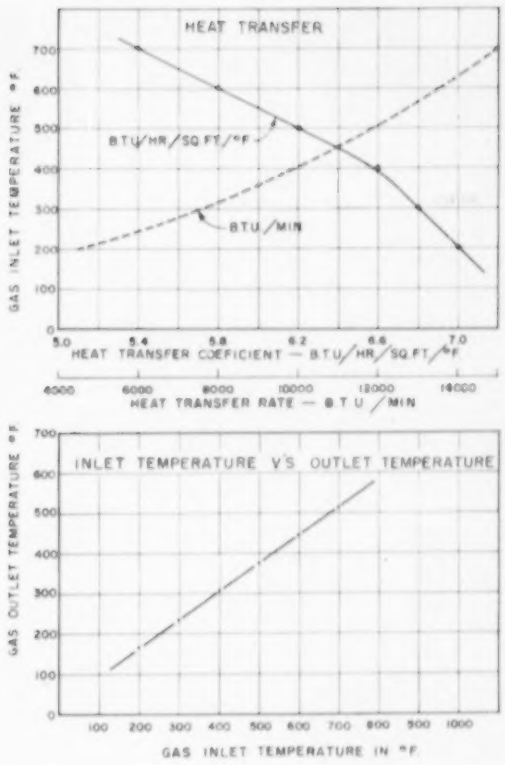


Fig. 6—Cooling-tower operating data at various temperatures for a 5-ft diam tower with gas volume at 10,000 cfm.

Table I. Experimental Treater on Blast Furnace Gas

Treater Inlet		Dust Concentration, Mg per Cu Ft		Treater Catch		Calculated Efficiency, Pct
Volume, cfm	Temperature, °F	Inlet	Outlet	Lb	Pct H_2O	
102	111	60.3	2.2	10.5	4.8	95.7
100	88	2.13	0.48	1.75	1.12	62.8
140	212	48.10	7.88	6.50	1.2	76.1
101	102	217.5	4.58	14.75	18.0	96.6
101	99	17.5	0.79	17.75	34.0*	93.0
116	63	1.92	0.80	2.25	6.3	95.6
116	68	103.2	0.89	8.25	2.1	98.9

* Some condensation in Treater.

Data for various operating temperatures are illustrated graphically in Fig. 6.

Operating data indicated that, in the case of the tube cooler and the tower operating with low gas volume, the rate of heat transfer was that which would be expected for streamlined gas flow. However, when volume was increased, the rate of heat transfer agreed closely with the relationship $H \propto G^{0.8}$, which is applicable to turbulent gas flow, although mass velocity is of the same order as that for the tubes. It may then be reasoned that turbulence has been imparted to the gas through the action of the high velocity jet inlet. Observation showed that turbulence persisted throughout the 17 ft height of the tower.

Practical application was made of those data in conjunction with the fact that, due to the turbulent gas flow, spray water could be evaporated rapidly, augmenting cooling to a calculated degree. Two separate tower arrangements were designed and installed to cool the high antimony and arsenic-bearing gas produced in the refining of silver. This gas

Table II. Operating Data for Trombone Tube Cooler

Inlet Temperature, °F	Outlet Temperature, °F	Temperature Drop, °F	Volume Cfm at Conditions, Avg	Volume Cfm at Stp	Gas Velocity, Ft per Sec	Mass Velocity, Lb per Sec per Sq Ft	H, Btu per Min	U, Btu per Hr per Sq Ft per °F
356	302	54	1725	1020	9.15	0.435	1058	0.60
358	300	58	1735	1030	9.2	0.436	1150	0.66
494	411	83	2050	1050	10.9	0.445	1670	0.65
536	438	98	2320	1140	12.3	0.484	2160	0.77
542	424	118	2020	1013	10.7	0.430	2310	1.10
574	444	130	1750	900	9.3	0.380	2250	0.75
576	456	120	1830	874	9.7	0.370	2020	0.68

H = rate of heat transfer, U = coefficient of heat transfer, and Q = quantity of heat.

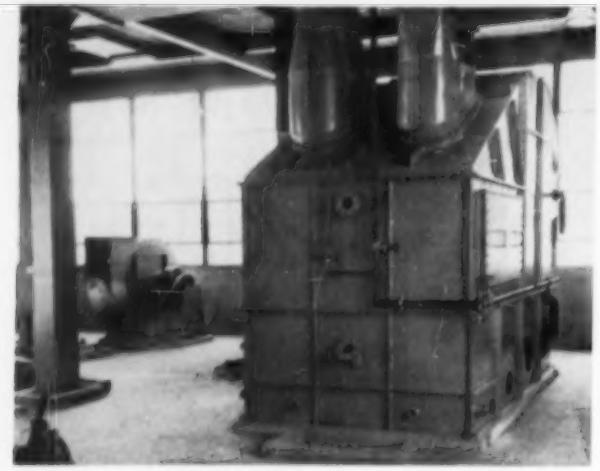


Fig. 7—View of a 20,000 cfm Doyle scrubber under construction.

is corrosive, due to the presence of some fluorine, and it is necessary to limit the amount of cooling effected by the evaporation of water.

Operating data and design requirements were as outlined below:

	Case 1	Case 2
Avg gas volume, cfm, stp	3700	5370
Avg gas temperature, °F	820	703
Water content, lb H_2O per lb dry gas	0.003	0.0286
Installed bag area, sq ft	3500	7000
Allowable volume, cfm	8700	17,400
Type of bag	Wool	Wool
Gas temperature, baghouse inlet, °F	210	210
Max dew point desired, °F	110	110

For Case 2, on the basis of the known data it was calculated that a 5x17 ft high tower would reduce temperature to about 540°F by radiation and convection. For a maximum dew point of 110°F it was possible to evaporate 12.7 lb H_2O per min, dropping the gas temperature to 395°F. To further lower the temperature to 210°F a calculated 506 lb of tempering air would be required. The final baghouse volume would then be 17,500 cfm (dry) with a dew point of 89°F.

The tower was set up on this basis, and its performance over the past two years has closely paralleled the design data. It may be noted that since its erection, wool bags in the baghouse have been replaced by Orlon bags, and the inlet gas temperature has been allowed to increase to 260°F. With this modification, water has not been used for auxiliary cooling.

After the operation of this cooling tower had proved satisfactory, a similar arrangement was designed and built for Case 1. Due to the higher gas temperature, a controlled volume of spray water is admitted at 300 psi for additional cooling. The tower has remained dry, indicating complete evaporation of the water.

Dust Recovery From Wet Gas

In addition to those gases already discussed, there is a third type from which dust and fume must be recovered, namely, a wet, corrosive gas at relatively low temperatures. In the Cominco sintering operation, this type of gas is a product of the wet-mix drying section of the plant and also of a great many ventilation outlets. Obviously, a baghouse or electrostatic precipitator is not suitable equipment

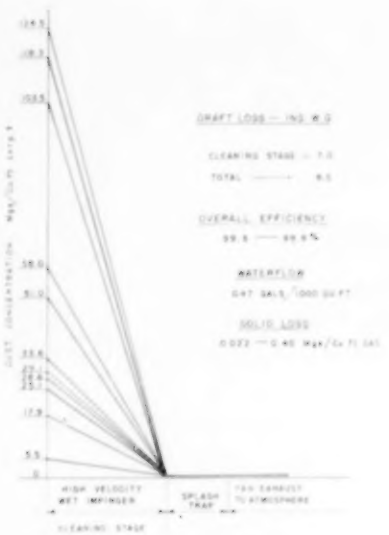


Fig. 8—Experimental data for the Doyle wet scrubber.

for dust recovery, and some type of wet scrubber must be employed.

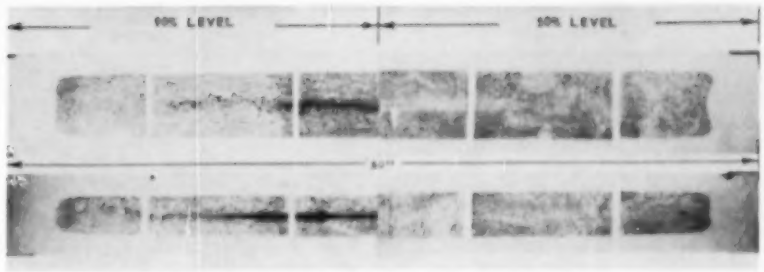
A highly efficient, compact unit, of simple design and utilizing no complicated or moving parts—the Doyle scrubber—has been developed by Cominco. These units operate on the principle of high velocity impingement of the dirty gas into water. Solid particles are separated from the gas stream to produce a sludge which is continuously removed. For rotary dryers, where large multiple units designed to handle 35,000 cfm of gas are installed, the slime discharge is continuously pumped to a bank of liquid cyclones for removal of solids, the cyclone overflow being returned to the scrubbers. The solution is normally acid, with a pH of 2. Lead-lined construction holds corrosion to a minimum.

The smaller units recovering dust from ventilation gas vary in size and detail, depending on location and service. Fig. 7 shows a view of a scrubber unit under construction.

Percentage dust recovery of an installation can be predetermined by test work, and performance characteristics of dust are used as the basis for design. With the various smelter installations in operation, recovery efficiencies are in the range of 98 to 99+ pct. Fig. 8 illustrates the dust recoveries obtained from a test unit.

A new piece of equipment in the field of wet collection, the Doyle scrubber has been found to be very effective for treating wet or dry gases. In some cases it has been installed to supplement conventional equipment, thereby increasing the efficiency of the overall installation, but usually, with new installations, the Doyle scrubber is used without preliminary equipment. Preconditioning of the gas is normally not required, but for certain applications where the dust is extremely difficult to remove due to its fineness or other peculiar quality, the gas may be preconditioned by water sprays, steam, or ionization.

The Doyle scrubber is used widely throughout Cominco's chemical and metallurgical operations; about thirty units have been installed in the lead smelter with capacities ranging from 3000 to 35,000 cfm. Patents on the scrubber have been obtained in a number of countries, including U. S. and Canada.



Sulfur prints of transverse sections of slabs, showing segregation at the 50 and 90-pct ingot levels. Top view is from a 29-in. ingot and bottom is from a 22-in. ingot. Rimmed steel.

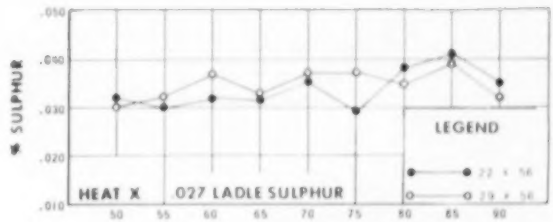
Higher Rolling Mill Output Stirs Inquiry Into Ingot Thickness

INCREASED use of high-speed, high-capacity continuous rolling techniques is causing steel men to take a searching look at means of ensuring uniform quality in large size rimmed ingots where segregation tends to be greatest. Efforts are being made to solve this problem, one of the oldest in the industry—segregation of impurities, particularly sulfur.

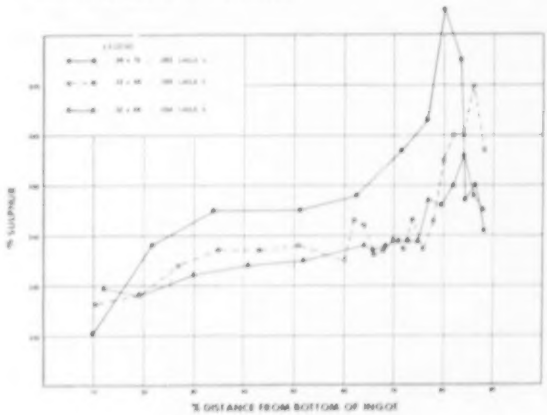
This review is abstracted from two recent studies on the subject, one by J. S. McNairn of Ford Motor Co., entitled *Ingot Thickness and Its Effects on Drawing Quality*, and the other by W. H. Mayo, S. B. Prellwitz, and M. B. Jacobs all of U. S. Steel Corp., entitled *Effects of Ingot Thickness on Quality of Rimmed Steel*. These were presented in their original form at the National Open Hearth Steel Conference, Cincinnati, April 1956.

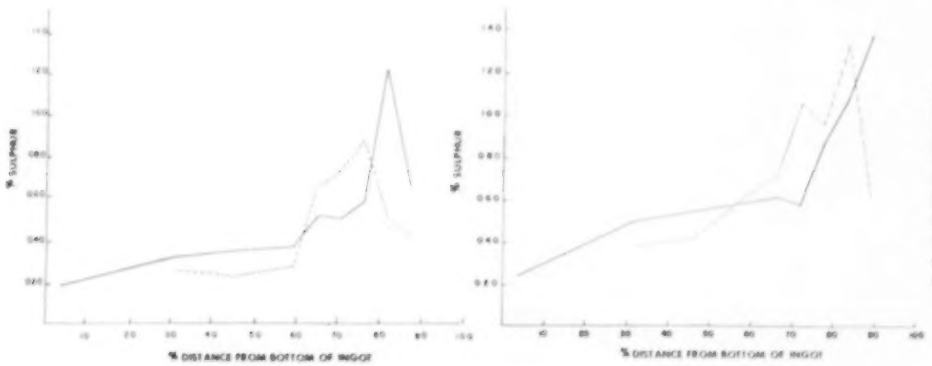
Tests have been made both on slabs and sheets to determine what effect various ingot thicknesses have on the pattern of sulfur segregation. These reveal that thicker ingots have their peak segregation at a lower level, often with two or more peaks occurring instead of just one. In the resulting sheets, peaks occur only when ladle sulfur is high, as shown by the center steel analyses at right. Carbon segregation did not show any relation to ingot thickness.

Variation in the position of segregation peaks was as much as 5 pct for no apparent reason. It was, therefore, concluded that there were additional factors which may affect segregation characteristics to an equal or even greater degree than ingot thickness. Experiments to determine the nature of these factors are continuing.



Effect of both ladle sulfur and ingot thickness on segregation in sheets is shown in the graphs above and below. Both are center sheet sulfur analyses for rimmed steel. At bottom are shown curves for high ladle sulfur ingots, with the thicker ingot having a greater peak. The top curves show that at low ladle sulfur, ingot thickness has a negligible effect on sulfur segregation in the sheets.





Distribution of sulfur in longitudinal section of slabs from 23x57-in. (solid line) and 29x57-in. (dotted line) ingots. Left and right curves are for rimmed ingots with 0.027 and 0.035 center line ladle sulfurs, respectively.

Acidity Control In Zinc Electrolysis

Originally developed for the zinc industry, the acidity control instrument described herein may be used as a time saving control method in any industry where a simple relation exists between conductivity of an electrolyte and the concentration of one of its constituents.

by Georg Steintveit

A convenient system of acidity control and maintenance of an accurate flow of purified solution to electrolytic cells is effected by a three-step operation: 1) collection of samples from the various cells; 2) determination of acidity by titration in the plant laboratory; and 3) regulation of cell feed, based on estimated acidity figures. In principle, there is no difficulty in replacing chemical titration by determination of specific gravity or the conductivity of the cell acid; however, no saving of labor can be expected by introduction of these methods as long as the sampling of cell electrolyte is maintained and determination of the sulfuric acid concentrations is performed in the plant laboratory. Reduction in control work, with fewer men, and the possibility of keeping a more uniform acidity will result only when means are found to inform the operator of the acidity at the moment that regulation of feed is required.

Relation Between Acidity and Conductivity

Fig. 1 gives the fundamental relationship between acidity and specific conductivity of sulfuric acid-zinc sulfate electrolyte at different temperatures. An increase of 1 gpl of H_2SO_4 corresponds approximately to a conductivity of $0.002\Omega^{-1} \times cm^{-1}$. The curves show that no accurate determination of acidity can be effected without taking the temperature of the solution into consideration. This error may be neglected, provided temperature fluctuations are kept within narrow limits. However, when variations between individual cells reach $\pm 10°C$, compensation is a necessity.

Conductivity Control Equipment

The standard laboratory method for accurate determination of the conductivity of electrolytic solutions is the *Kohlrausch Compensation Method*,[1-4] consisting of a Wheatstone bridge circuit, equipped with zero indicator to determine the conductivity from the column of liquid established by immersing two platinized platinum electrodes[4,5] in the electrolyte.

A conductivity measuring instrument applied to the determination of acidity in the tank house will have to work in the tremendously strong magnetic fields surrounding the buss bars. These fields are of such strength as to disturb the normal function of the indicators, transformers, and relays. Because of the relatively small rise in conductivity with increasing acidity, a measuring instrument must possess an extraordinary sensitivity, and must, in addition, compensate for a large polarization effect[6,7] occurring during measurements, even when platinized platinum electrodes and voltage of audio frequencies are applied. Important work has been performed to design equipment for accurate conductivity measurements.[8-10] None, however, are in conformity with the above requirements. The same is true with the various commercial conductivity instruments on the market.

Quite a different method is described by T. T. Moore and L. A. Painter.[11] Here, *the resulting current is measured*, when impressing a constant voltage through a *U*-shaped tube of electrolyte of constant length and cross section. A conductivity probe is inserted in the cell by the operator, and current passing through the *U*-shaped tube of acid controls several groups of different colored lamps, visible to the operator at all locations in the cell room.

According to this principle, the main difficulties of the Kohlrausch method are avoided, as the voltage is so large that polarization on the electrodes may be neglected when using ordinary alternating current. Furthermore, sensitive electrical equipment is located outside the strong magnetic fields.

The drawbacks of such an instrument are that the system calls for a rather extensive arrangement of interconnecting cables all over the tank house. Also, inaccuracies of acidity determination may be great, as there exists no possibility for compensation of conductivity variations due to individual temperature fluctuations from cell to cell, when the device once has been adjusted for a desired range.

The New Method of Acidity Control

A new conductivity measuring device consists of two main parts: an extremely sensitive measuring bridge, and a plastic floater in which platinum electrodes and a thermometer are assembled.

The Measuring Bridge: The measuring bridge, which incorporates some original electronic circuits, is based upon the Kohlrausch compensation principle, but has overcome all the difficulties previously discussed, and accordingly is fit to work within the strong magnetic fields prevailing in a tank house. The amplified signal of the resistance bridge is rectified and controls the operation of a cathode ray in-

GEORG STEINTVEIT is Chief of the Control and Research Dept., Det Norske Zinkkompani A/S, Odda, Norway.

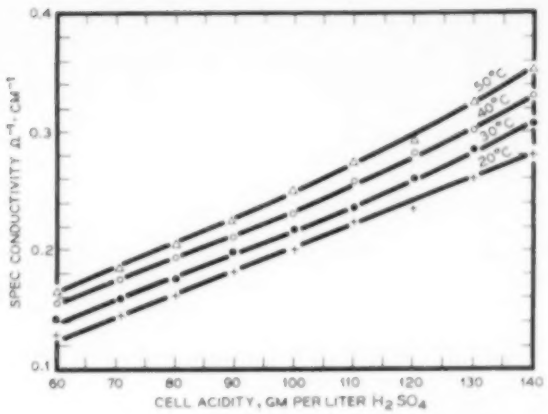


Fig. 1—Acidity-conductivity relationship for H_2SO_4—$ZnSO_4$ electrolyte.

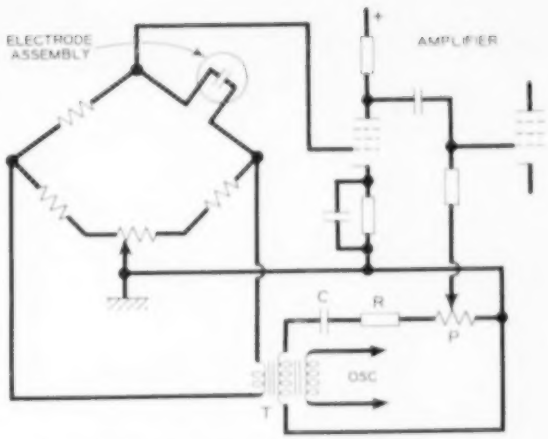


Fig. 2—Wheatstone bridge and polarization control circuit.

dicator. A push pull oscillator supplies ac voltage of audio-frequency to the Wheatstone bridge. It is battery-operated and of sufficiently light-weight to be carried with ease, giving acidity readings of ±0.5 gpl H_2SO_4, compensating for individual temperatures in different cells. It may rapidly be calibrated to eliminate the influence of variations in electrolyte composition from day to day or from one week to another, as well as the influence of dimensional discrepancies of different electrodes.

Due to the considerable polarization effect previously mentioned, the electrodes will not present a pure resistance to the bridge terminals but a resistance in series with a capacitance. Accordingly, for the bridge to show a perfect balance, one of the bridge elements should contain a continuously variable reactance, but with the polarization capacitance concerned, variable reactance is not practical.

A special electronic circuit, supplying a compensation voltage for establishing a *polarization control*, has contributed highly to the success of the instrument. The problem is solved by compensating the influence of the reactance by introducing, across the indicating diagonal of the bridge, an additional voltage of similar amplitude but opposite sign to the disturbing voltage. By this precaution, it has been possible to obtain a distinct adjustment of the cathode ray indicator. Fig. 2 shows the bridge, together with the first amplifier circuit leading to the indicating part of the instrument. The bridge voltage is delivered by a transformer, *T*, supplied with an additional winding. Over a phase turning network, this winding delivers the compensating voltage, being introduced just after the first amplifier stage so as not to disturb the bridge circuit. The phase position of the compensating voltage is kept constant, whereas the amplitude of the voltage may be varied by means of the potentiometer, *P*. The phase may also be controlled by chosing different values of the resistance, *R*, and/or the condenser, *C*.

Temperature correction is very simply effected by establishing a relative movement of the acidity scale in relation to a temperature correction scale, calibrated at standard temperature conditions. The bridge receives power from a 180v, 10 ma anode battery unit, and a 6 v, 10 amp zinc-silver accumulator.

The Floater: Electrode and Thermometer Assembly: The second part of the acidity tester is the floater, in which the platinized platinum electrodes and the thermometer are assembled. The electrode terminals, completely enclosed in the floater, are connected to the bridge by means of a flexible cable.

Procedure for Determination of the Acidity

Determination of the acidity of cell electrolyte is performed in the following manner: 1) the switch is turned on. After approximately 15 sec the tubes are warm, and the measuring bridge is ready for the acidity determination; 2) the plastic floater is placed in the electrolyte and the temperature is read; 3) the acidity scale is turned until the temperature mark on the scale indicates the cell temperature on the temperature correction scale; and 4) the push button is pressed by the right hand, and the potentiometer dial turned with the left until the cathode ray indicator shows a maximum of dark field. The bridge is now in equilibrium. The number of gpl H_2SO_4 given on the scale is the acidity of the cell acid.

Maintenance and Performance

The measuring bridge is built for relative rough handling and may be treated like an ordinary portable radio. It is important to secure good contacts between the electrodes and the bridge, and these are, therefore, protected by air and water-tight seals. The high-voltage battery is replaced when voltage drops below 150 v. A charging station is necessary for the accumulator. Charging is done when instruments are not in use.

Introduction of this method of acidity determination in electrolytic zinc production has resulted in maximum saving of manpower in the tank house control operation and in important improvements in regular maintenance of acidity.

References

[1] J. Livingstone, R. Morgan, and O. M. Lammert: *Journal* American Chemical Society, 1926, vol. 48, p. 1220.
[2] G. Jones and R. C. Josephs: *Journal* American Chemical Society, 1928, vol. 50, p. 1049.
[3] Heinz Gerischer: *Ztsch. für Elektrochemie*, Ber. Bunsenges. Physik. Chem., 1954, vol. 58, p. 9.
[4] T. Shedlovsky: *Journal* American Chemical Society, 1930, vol. 52, p. 1806.
[5] G. Jones and G. M. Bollinger: *Journal* American Chemical Society, 1931, vol. 53, p. 411.
[6] G. G. Jones and S. M. Christian: *Journal* American Chemical Society, 1935, vol. 57, p. 272.
[7] G. Jones and D. M. Bollinger: *Journal* American Chemical Society, 1935, vol. 57, p. 280.
[8] G. Jones and R. C. Josephs: *Journal* American Chemical Society, 1928, vol. 50, p. 1049.
[9] P. H. Dike: *Review of Scientific Instruments*, 1931, vol. 2, p. 379.
[10] T. Shedlovsky: *Journal* American Chemical Society, 1930, vol. 52, p. 1793.
[11] T. T. Moore and L. A. Painter: *Trans., AIME*, 1953, vol. 192, p. 1156.

Beta-Omega Age Hardening Means Stronger Zirconium Alloys

H. A. Robinson
J. R. Doig
M. W. Mote
C. M. Schwartz
P. D. Frost

The β-ω phase transformation, important in many titanium alloys, has been revealed in zirconium alloys. Hitherto unattainable tensile strength with adequate ductility is now feasible for certain zirconium alloys. It is expected that many new applications will result from this discovery.

HEAT treatments, developed recently for β-stabilized titanium alloys, such as the Ti-3 pct Mn-complex alloy (3 pct Mn-1 pct Cr-1 pct Fe-1 pct Mo-1 pct V), produce high strength with adequate ductility.[1] Success of these heat treatments came about after it was discovered that a brittle transition phase, designated ω, formed in binary alloys during the β-to-α transformation or aging cycle, and that overaging was necessary to complete the transformation: $\beta \rightarrow \beta + \omega \rightarrow \beta + \alpha$.[2, 3] The $\beta \rightarrow \omega$ reaction was definitely found to occur in Ti-Fe, Ti-Mn, Ti-Cr, Ti-Mo, Ti-V, and Ti-Ni. Some evidence of the phase has been found in complex alloys.[4]

Recent research with Zr-Mo and Zr-Cb-base alloys has revealed that the β-ω transformation can occur in zirconium alloys as well as in titanium alloys. For example, a Zr-5.5 wt pct Mo alloy was melted by the tungsten-arc, cold-mold process and fabricated into 0.070-in. sheet. Small specimens were solution heat treated for ½ hr in argon at 830°C (1526°F), which is in the β-phase field, and quenched in iced brine. They were subsequently aged in air at 480°C (896°F) up to 200 hr, and subjected to metallographic examination, Vickers hardness tests, and X-ray diffraction analysis. X-ray specimens were etched rod samples and were examined in a 57.3-mm Debye camera, using filtered iron radiation.

Fig. 1 correlates hardness changes and phase changes observed during aging of quenched specimens of the Zr-5.5 wt pct Mo alloy. In the quenched condition, the alloy consisted largely of retained β, with some ω, which had transformed from β during the quench. After aging 15 min at 480°C (896°F), hardness increased to over 450 Vhn; simultaneously the intensity of the ω pattern increased, and part of the β phase acquired a molybdenum content greater than the original 5.5 wt pct. Formation of this *partially* enriched β is detected by broadening of the X-ray reflections of β phase in the direction of increasing Bragg angle. It suggests that the zirconium ω phase, like that in titanium, has a relatively low solubility limit for β-stabilizing elements. After 2 hr at 480°C (896°F), the ω pattern became more intense, while β of original composition was no longer detectable with certainty. Partially enriched β and a fully enriched β existed at the same time. The latter was distinguished from the original and partially enriched β by the appearance of a discrete Debye ring at the high-angle ends of the diffuse enriched-β streaks. Hardness remained high—over 400 Vhn—for about 30 hr. After 50 hr at 480°C (896°F), the alloy had overaged to a hardness level of 375 Vhn and α had begun to form, although a strong ω pattern was still obtained. After 100 hr, the alloy had become quite soft, a strong α pattern was observed, the ω phase had almost disappeared, and the only β present was highly enriched in molybdenum. With continued aging the compound $ZrMo_2$ began to form, ω completely disappeared, and fully enriched β and α were present.

The transformations just described are similar to those which occur during the aging of quenched β-stabilized titanium alloys. The reactions $\beta \rightarrow \beta + \omega \rightarrow \beta + \alpha \rightarrow \alpha +$ compound are depicted for a Ti-4 pct Fe alloy in Fig. 2.[3] The Ti-4 pct Fe alloy, when quenched from the β region, consisted largely of β, but ω had also formed during the quench, with the result that considerable hardening took place.

After aging ½ hr at 427°C (800°F), ω, untransformed β, and enriched β were all present. As the ω pattern became more intense, enriched β replaced the β of original composition and, between 2 and 8 hr aging time, the hardness and resistivity of the alloy decreased markedly. Upon prolonged aging, ω was replaced by α and, finally only α and the compound TiFe were observed.

It will be noted that maximum hardness occurs in both the zirconium and titanium alloys during the early stages of ω formation, and that intense ω reflections may be obtained after some overaging or softening has occurred. This is not inconsistent with other age-hardening alloy systems. The ω particle size that effects maximum hardness need not necessarily be the same as that which causes maximum intensity X-ray patterns. As the ω particles grow larger, patterns should become sharper and more intense; it would also be expected that loss in coherency with the β matrix would occur and that the hardness would decrease.

Crystal structure of ω in a Ti-Cr alloy has been shown[5, 6] to be complex cubic, with 52 Ti and 2 Cr atoms to the unit cell, somewhat similar to that of γ brass. The unit-cell edge is about three times that of the parent β phase. The cell size has since been

H. A. ROBINSON, J. R. DOIG, M. W. MOTE, C. M. SCHWARTZ, and P. D. FROST are with Battelle Memorial Institute, Columbus, Ohio.

confirmed by Silcock, et. al.,[5] who studied a Ti-16 pct V alloy. Interplanar spacings of the ω phase obtained from X-ray diffraction patterns of the Zr-5.5 pct Mo alloy are shown in Table I. Crystal structure of zirconium ω was not determined, but it was established that the structure is not cubic, as can be seen from the data in Table I. Observed interplanar spacings were compared with values calculated for a unit cell with an edge three times that of the parent β, assuming the same intensities and Miller indices would occur as in titanium ω. Differences between the interplanar spacings thus calculated and those observed were found to range erratically from 0.0 to 1.4 pct. Yet, the error of film measurement for values below 1.45Å—region of lowest instrumental errors—was found to be only 0.2 pct or smaller. It must be concluded that differences of 0.6 to 1.4 pct are due to deviation from cubic symmetry, and that this new phase is not cubic in the aged condition. Likewise, the ω phase, observed in samples of this alloy as quenched from the β field, was noncubic.

However, the ω phase did appear to be cubic in one sample of a Zr-2.5 pct Sn-5 pct Cb alloy in the as-quenched condition after solution treating in the α-β field at 830°C (1526°F). Observed interplanar spacings of the ω phase having values below 1.4Å agreed within 0.2 pct with those calculated for a cubic cell of 10.66A. After aging 48 hr at 430°C (806°F), the ω phase in this alloy showed a transformation to the noncubic form. The ω pattern gained added reflections at 1.015 and 0.982Å, and the other interplanar spacings changed so that they agreed with the values of the noncubic ω in Table I.

Although the apparently cubic form of ω has been observed in only one sample, it may be concluded that there is a driving force to produce either form. It should be expected that mechanical properties would vary, depending on the form present, and this choice, in turn, might depend on alloy composition. It is not surprising that the cubic form of ω has been observed only in the as-quenched condition, since the phase might be held in cubic symmetry by the constraint imposed by coherency with the untransformed β.

The fact that the transformation $\beta \rightarrow \beta + \omega \rightarrow \beta + \alpha \rightarrow \alpha +$ compound has been found in zirconium alloys has considerable practical significance. It explains brittle behavior sometimes observed in the past when certain zirconium alloys have been quenched following a heat treatment. An understanding of the transformation should make it possible to develop heat treatments which will improve the usefulness of zirconium alloys. In the present research, strengths as high as 200,000 psi have been obtained in zirconium alloys containing molybdenum or columbium by heat treatments designed to complete the $\beta \rightarrow \omega \rightarrow \alpha$ transformation. Improvements in both strength and ductility are now being sought.

It is expected that the ω phase could form in any zirconium alloy in which the β phase may be retained during the quench. Elements, which have appreciable solubility in zirconium β phase and which do not readily form eutectoid intermetallics, should be most amenable to age hardening. Alloys of zirconium with molybdenum, columbium, silver, tantalum, thorium, uranium, or vandium appear, from their phase relationships, to offer promise in this respect.

References

[1] W. M. Parris, P. D. Frost, and J. H. Jackson: *Heat Treatment of High-Strength Titanium-Base Alloys, Trans. ASM*, 1954, vol. 46, p. 568.

[2] P. D. Frost, W. M. Parris, L. L. Hirsch, J. R. Doig, and C. M. Schwartz: *Isothermal Transformation of Titanium-Manganese Alloys, Trans. ASM*, 1954, vol. 46, p. 1056.

[3] WADC Technical Report No. 54-355, Parts I and II, Battelle Memorial Institute, June, 1954, and February, 1955.

[4] A. E. Austin and J. R. Doig: *Structure of the Transition Phase, Omega, in a Titanium-Chromium Alloy*. To be published.

[5] J. M. Silcock, M. H. Davies, and H. K. Hardy: *Structure of the Omega-Precipitate in Titanium-16 Per Cent Vanadium Alloy*, Nature, April 23, 1955, vol. 175, p. 731.

Table I. X-Ray Powder Diffraction Pattern[a] of Omega Phase in Aged Zr-5.5 Pct Mo Alloy[b]

Visual Intensity[c]	Interplanar Spacings, A: Observed	Interplanar Spacings, A: Calculated on Basis of $a_0 = 10.66$ A[d]	$h^2 + k^2 + l^2$ Assumed in Calculated Spacings	Difference Between Observed and Calculated Interplanar Spacings, Pct
f	3.12	3.09	12	+1.0
vvs	2.50	2.52	18	−0.8
m	1.96	1.95	30	+0.5
ms	1.78	1.78	36	0.0
vvf	1.65	1.65	42	0.0
mf	1.56	1.54	48	+1.3
vs	1.453	1.455	54	−0.1
s	1.328	1.316	66	+0.9
f	1.317			
ms	1.257	1.260	72	−0.2
vs	1.129	1.127	90	+0.2
vs	1.065	1.058	102	+0.7
s	1.029	1.029	108	0.0
ms	1.015	1.001	114	+1.4
vs	0.982	0.976	120	+0.6

[a] Obtained from etched rod sample in a 57.3-mm Debye camera, using filtered iron radiation.

[b] Solution treated ½ hr at 830°C (1526°F), quenched into iced brine and aged 48 hr at 480°C (896°F).

[c] s = strong; m = medium; f = faint; v = very.

[d] Assumed unit-cell edge three time the 3.564Å lattice constant of β phase.

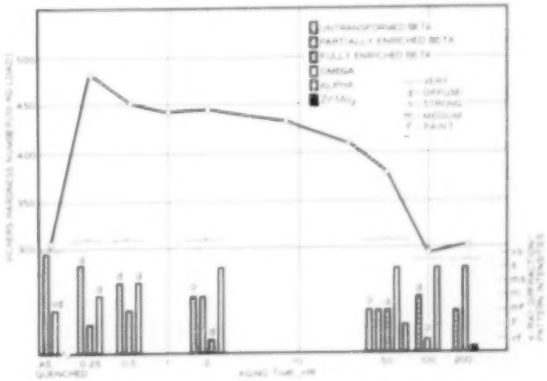


Fig. 1—Effect of aging at 480°C on the hardness and X-ray diffraction pattern intensities of a Zr-5.5 wt pct Mo alloy quenched from 830°C.

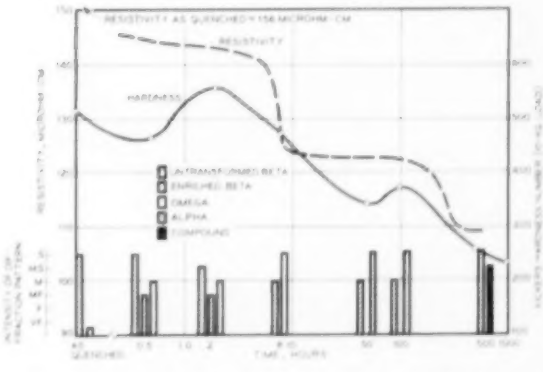
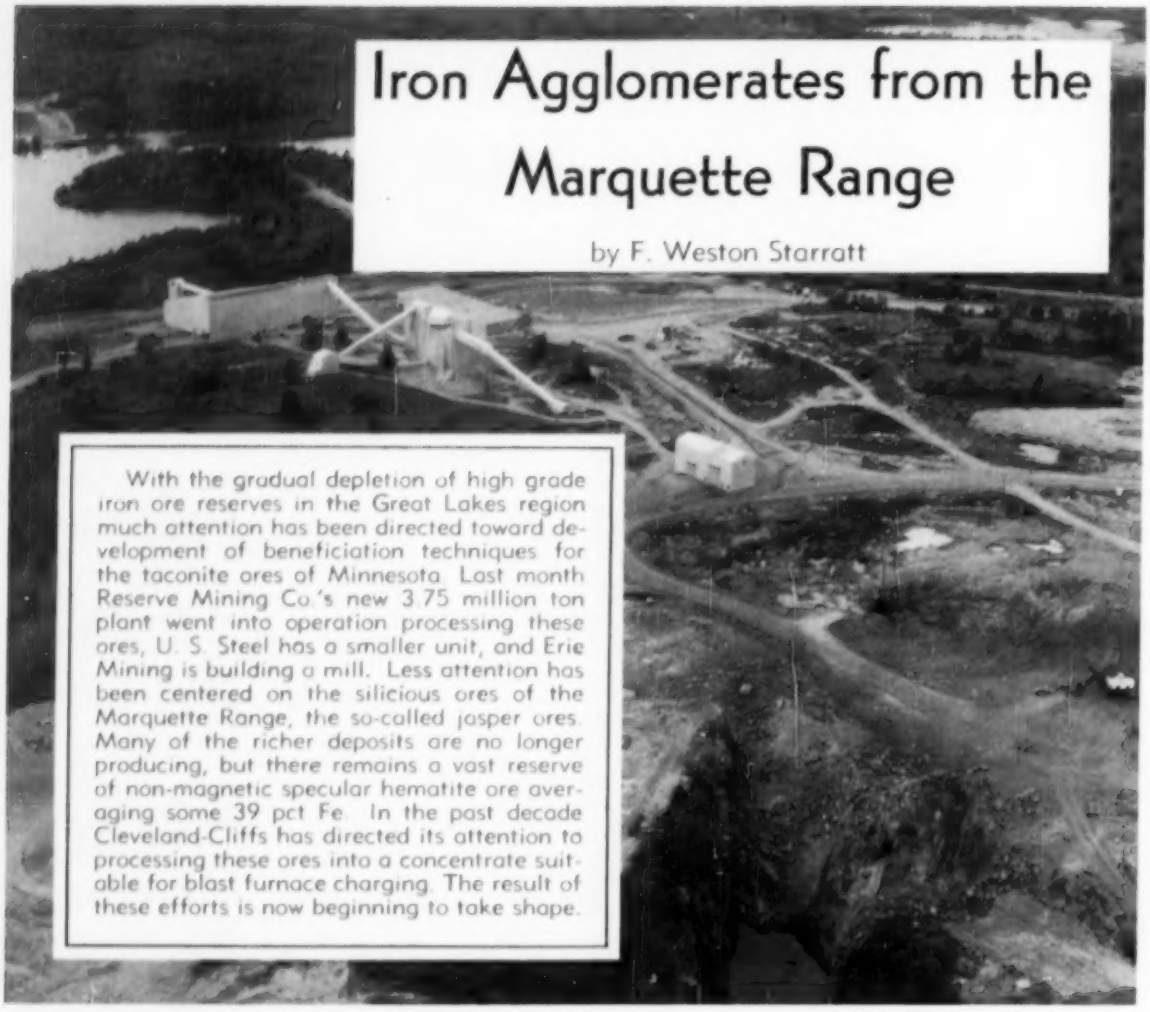


Fig. 2—Effect of aging at 427°C on the resistivity, hardness, and X-ray diffraction pattern intensities of a Ti-4 pct Fe alloy quenched from 927°C.

Iron Agglomerates from the Marquette Range

by F. Weston Starratt



With the gradual depletion of high grade iron ore reserves in the Great Lakes region much attention has been directed toward development of beneficiation techniques for the taconite ores of Minnesota. Last month Reserve Mining Co.'s new 3.75 million ton plant went into operation processing these ores, U. S. Steel has a smaller unit, and Erie Mining is building a mill. Less attention has been centered on the silicious ores of the Marquette Range, the so-called jasper ores. Many of the richer deposits are no longer producing, but there remains a vast reserve of non-magnetic specular hematite ore averaging some 39 pct Fe. In the past decade Cleveland-Cliffs has directed its attention to processing these ores into a concentrate suitable for blast furnace charging. The result of these efforts is now beginning to take shape.

THE opening of a new large-scale beneficiation plant is always news, but the start-up of Cleveland-Cliffs Iron Co.'s Eagle Mills near Ishpeming in Michigan's Upper Peninsula early in October is of particular interest because of the completely different type of operation being carried on at this plant.

The ore boat which left Marquette, Mich. on the 3rd of October bound for the plant of Wisconsin Steel Division of International Harvester, not only carried the first output of this new mill, but also carried the first agglomerate made from the Upper Peninsula's jasper ore, the first commercial output from an updraft traveling—grate furnace, and the first large-scale commercial application of the balling disk, also called the *flying saucer*, to the agglomeration of an iron flotation concentrate.

This was not the first shipment of an iron concentrate made from these jasper ores. Since the opening of the Humboldt mine and flotation mill in this same area in March 1954, the Ford Motor Co. has been taking its entire output of concentrates for Ford's sintering plant. The Eagle Mill does, however, mark the first time that the fine flotation concentrates have been made into hardened pellets for direct blast furnace charging.

Jasper ore from new Republic open pit

Iron concentrate now being received at Eagle Mills is mined and milled at Republic Mine, located on the Marquette Range some 2 miles by rail. The deposit is owned by Cleveland Cliffs, and the mill, while operated by them, is owned by a firm known as the Marquette Iron Mining Co., a venture in which Cleveland Cliffs holds 47.5 pct of the stock with the rest divided between, Jones & Laughlin Steel, International Harvester, Inland Steel, and Wheeling Steel.

At Republic, underground mining commenced about 1870, but the last shipment of direct smelting ore was made in 1937. What remained was a lower grade ore body of specular hematite, physically united with a cherty material in a stratified schistlike formation. It is covered with an overburden varying in depth up to 50 ft.

In 1947 a diamond drilling program was undertaken by Cleveland Cliffs. This proved workable ore reserves to be in excess of 100 million tons when mining by open pit techniques to a depth of 500 ft.

Republic Mill utilizes technique developed at Humboldt

The Republic mill began operations in April 1956 as the second jasper concentrating unit on the Mar-

quette Range. The first was located at Humboldt Mine, only a few miles distant. This 300,000 ton capacity operation is a joint venture of Ford and Cleveland-Cliffs. At present the output is being shipped directly to Ford, but at a later date it is anticipated that its output will also be agglomerated at Eagle Mills. The mill at Republic, with a capacity for handling some 600,000 tons of ore annually, utilizes a flow sheet similar to the Humboldt operation.

Jasper ore unsuitable for magnetic separation

Both Humboldt and Republic ores have similar characteristics, and neither lend themselves to direct magnetic separation. For some time experimental work had been conducted on a technique using a reducing roast followed by magnetic separation. This work is still being continued, but it has not proven feasible, at least for large scale production. The technique finally adopted for both plants is a flotation process similar to that frequently employed in separating non-ferrous minerals from waste. This is, so far as is known, the first time that flotation has been commercially applied to the separation of iron oxide ores.

Three step crushing operation used

At Republic, from 3500 to 4000 tpd of mill feed, averaging some 39 pct Fe, is supplied by the open pit. Mining operations use a bench height of 40 ft, with a jet piercer for primary blast hole drilling in the hard silicious ore. Broken ore is loaded by an electric shovel equipped with a 5 cu yd dipper into 34-ton diesel powered trucks for haulage to the crushing plant.

Crushing is a three step operation which reduces the ore to —½ in. The ore is discharged into a gyratory crusher, screened, and the +2 in. ore fed into a 7-ft Symons cone crusher. After a second screening, the +½ in. ore is fed into the tertiary crusher, a 7-ft shorthead cone crusher. At the rate of 500 tph the crushed ore is conveyed to the feed bin in the mill building. This bin is filled during one shift operation of the crushing unit, and it provides the mill and flotation sections with sufficient raw material for round-the-clock operation.

At Republic, two almost-identical milling-flotation units

At the head of each milling-flotation unit is a 9x12-ft rod mill which discharges into a 11-ft diam Hardinge ball mill, operating in closed circuit with a 14-ft hydroscillator. The crushed ore is ground to —65 mesh in this operation.

The hydroscillator overflow is pumped to a 24-in. cyclone followed by a bank of 6-in. cyclones for desliming and thickening. The underflow from the 24-in. cyclone discharges into a spiral densifier for further thickening. The 6-in. cyclone overflow, or slimes, which represents some 2 pct of the weight of the ore being handled at the mill, is piped to the tailing pond. While it carries some 30 pct Fe, it is much too finely ground to be treated economically by flotation or gravity methods.

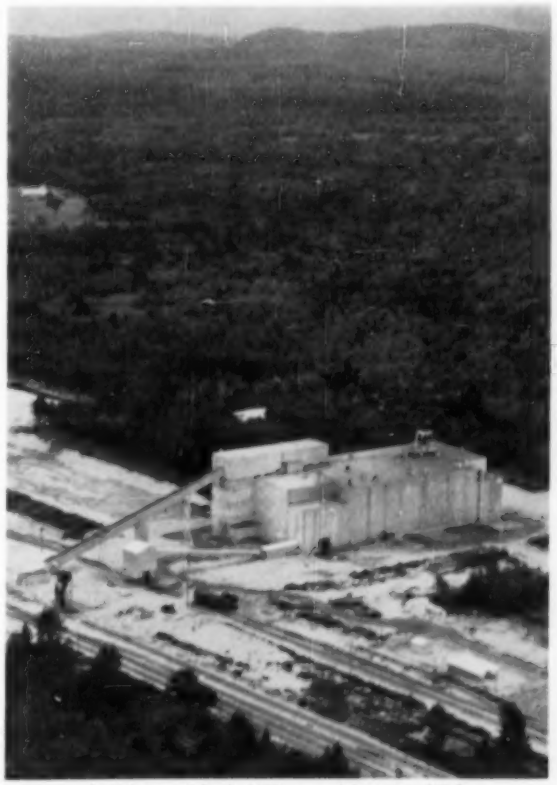
The thickened product from the densifier flows by gravity to the first of four conditioners, while the underflow from the 6-in. cyclones discharges into the fourth conditioner. Flotation reagents—a fatty-acid collector, bearing the trade name Asimtol of the Arizona Chemical Co., and a frother—are added to the first conditioner in the amount of 1.2 lb per ton of ore. The conditioned pulp is pumped to the flotation cells.

The usual arrangement of roughing, cleaning, recleaning, and scavenger cells is used. Flotation tailings carry 7.5 pct Fe, while the concentrate after passing through a thickening tank and dewatering filter, carries about 63 pct Fe, 8 pct SiO_2, and 3 pct moisture. Each flotation unit is capable of treating some 80 tons of feed per hour. In the over-all operation only some 9 pct of the available iron, plus that iron chemically combined with silica, is lost.

In the past few months since Republic Mill went into operation, concentrate has been stockpiled, but now, with Eagle Mills also in operation, the concentrate is discharged into railroad cars for direct transport to Eagle Mills, some 32 miles distant.

At Eagle Mills, Republic concentrate agglomerated into direct charging pellets

Eagle Mills agglomerates the —65 mesh iron concentrate into sizes sufficiently large to be handled in the blast furnace. But, to produce a satisfactory pellet it is necessary to start out with a very finely ground material —65 mesh is much to coarse! So, the first step is a grinding operation, and for this a Hardinge Tricone ball mill is used to reduce the concentrate to 65 pct —325 mesh. The finely ground material is thickened and dewatered.



Aerial view of Eagle Mills, near Ishpeming, Mich.

The unfired green pellets are a blend of the concentrate with 2.5 pct ground limestone, 4 pct ground anthracite coal, and 0.5 pct bentonite. A Hardinge Thermomill is employed for grinding the first two, while the latter is received at the plant in sufficiently fine particles. Bentonite serves to bind together the wet particles of concentrate, while limestone promotes the formation of a low temperature slag, which holds the dried pellets together in the lower temperature region of the furnace. In addi-

tion, it is presumed that the inclusion of limestone will tend to promote better blast furnace performance with these pellets.

Balling Disks, or Flying Saucers, used for agglomeration

The concentrate, bentonite, and ground limestone join each other at the balling disks. Eagle Mills has four of these 18 ft balling disks, which revolve in a plane enclined some 50° to the horizontal. The blend is deposited by conveyor in the center, and, as it tumbles in the disk, it forms round particles which grow larger as they pass over successive lips to the outer edge of the disk. Ground coal is added in the last lip of the disk in order to coat the agglomerate with a thin layer of fuel for the heat hardening operation. The pellets discharged from the disk range in size from $+\frac{3}{8}$ in. to $-\frac{1}{2}$ in.

Pellets heat-hardened in updraft traveling-grate furnace

The design of this furnace has certain similarities to the traditional Dwight-Lloyd sintering machines, and it has, in fact, been designed by the McDowell Co. The most significant difference with this traveling grate furnace is the updraft principle which permits, not only a thicker layer of material to be treated, but also permits an extended high temperature treating of the green pellets without damaging the malleable iron grate bars. The grate conveyor is 6 ft wide and 223 ft long; the first 168 ft are the firing zone, and the remainder serves to cool the pellets. The furnace is capable of heat hardening some 2000 tpd of pellets at a maximum temperature of some 2500°F. The grate speed is 30 in. per minute.

The hearth layer for the furnace, deposited directly on the grate, consists of 4 in. of $+\frac{1}{4}$ in. $-\frac{1}{2}$ in. return pellets, screened out at the exit end of the furnace, plus a certain quantity of ground ignition coal. The layer is subjected to a maximum of 5 in. downdraft as it passes into the ignition box. Propane is used to ignite the top of the layer, and it passes on over five downdraft wind boxes which ignite thoroughly.

Further along the grate, 8 in. of green pellets are deposited on the hearth layer as it moves onto the first of 23 updraft wind boxes. The updraft causes the hearth layer to ignite the green pellets, and at later stages three more 8-in. layers of pellets are deposited. Each of these layers is successively ignited, and toward the end of the furnace, there are, thus, a total of 32 in. of hardened pellets and a 4 in. hearth layer on the grate. At this stage a draft of 20 in. is required for firing.

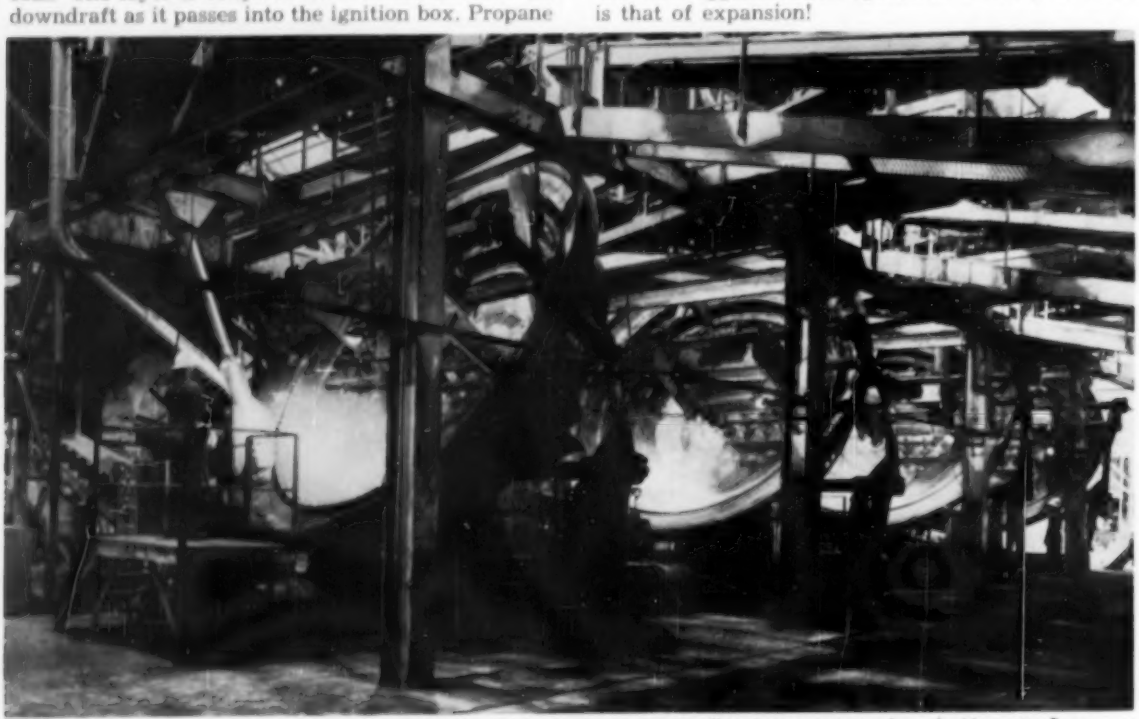
The heat hardened pellets are discharged onto a screening machine. Plus $\frac{1}{2}$ in. goes to the waiting railroad cars, $-\frac{1}{4}$ in. is reground in the ball mill, and the fraction in between these is used for the hearth layer.

1957 expected to show full-scale pellet production

The heat hardened jasper iron pellets are transported by rail to the docks at Marquette, 7 miles distant. While only some 70,000 tons of these 63 pct Fe pellets are expected to be moved out this year, it is anticipated that next year will witness full-scale production of 600,000 tons of high grade iron pellets for the steel industry. There is a ready and waiting market for these pellets. The only direction in which this new agglomeration operation is likely to move is that of expansion!

Addendum

F. C. Collin and O. A. Grytting, authors of *A New Approach in Electric Pig Iron Smelting*, which appeared in the October, 1956, JOURNAL OF METALS, wish to acknowledge the participation of Christiania Spigerverk in Oslo, Norway in the later stages of the experimental work, from which most of the data in the paper was extracted.



First large scale commercial flying saucer installation, used for agglomerating iron flotation concentrates from the Marquette Range.

Rate and Mechanism of the Sulfur Transfer Reaction

The rate of sulfur transfer between carbon-saturated iron and oxide slags has been measured in an apparatus which permits concurrent measurement of CO evolution. Slag and metal samples were analyzed to observe the movements of other elements besides sulfur. The results are interpreted to show that an electrochemical mechanism is possible. The mode of CO evolution is clarified by treatment of the results in terms of the *two-film* hypothesis of reactions between two liquid phases.

by S. Ramachandran, T. B. King, and N. J. Grant

MANY investigations of the rate of the sulfur transfer reaction between carbon-saturated iron and blast furnace type slags have been made.[1-5] It is evident that the reaction is complex, the rate being affected by the presence of elements dissolved in the metal that are readily oxidized and therefore capable of existing in the slag phase. Thus Goldman, Derge, and Philbrook[5] have shown that carbon, silicon, manganese, and aluminum, in order of increasing effectiveness, accelerate sulfur transfer from iron containing these elements to blast furnace type slags.

Quantitative information is still, however, not available on the relation between what have been termed side reactions, such as silicon transfer and CO evolution, and the sulfur transfer reaction itself. In other words, the stoichiometry of the reaction has not been investigated.

In the present investigation, the transfer of all reacting elements and the evolution of CO have been measured simultaneously in order to establish the mechanism of the reaction which occurs in practice. Information of this nature cannot be deduced from equilibrium studies.

It should be pointed out that in kinetic studies of this type quantitative conclusions are applicable only to the system studied. This restriction should be borne in mind when attempts are made to compare results from different investigations.

S. RAMACHANDRAN, Associate Member AIME, formerly Research Assistant, Dept. of Metallurgy, Massachusetts Institute of Technology, is now Assistant Development Engineer, Mill Research and Development Dept., Youngstown Sheet and Tube Co., Youngstown, Ohio. T. B. KING and N. J. GRANT, Members AIME, are Assistant Professor and Associate Professor, respectively, Dept. of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

TP 4355C. Manuscript, May 14, 1956. New York Meeting, February 1956.

Apparatus

The apparatus used enables slag and metal samples to be taken at frequent intervals and also provides a continuous record of the amount of gas evolved. A sketch of the apparatus is given in Fig. 1. It may be considered in three sections: 1) furnace section, 2) blank volume section, and 3) pressure measuring section.

The furnace section is shown in detail in Fig. 2. It consists of two graphite crucibles, *C* and *D*, super-

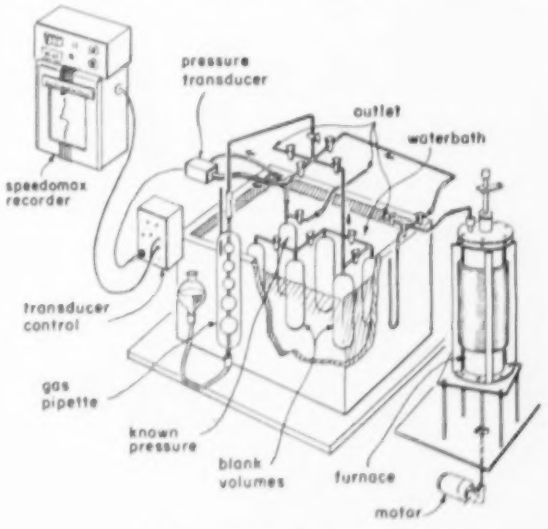


Fig. 1—General view of apparatus.

The Transactions papers appearing in the Journal of Metals during 1956 will subsequently appear in AIME Transactions Volume 206, and may be permanently referenced to that volume.

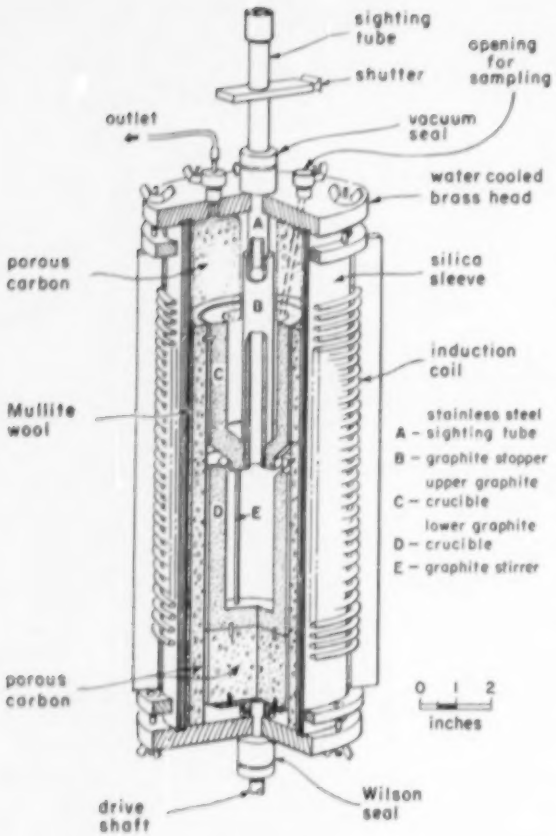


Fig. 2—Arrangement of furnace section.

posed one on the other. Metal is melted in the upper graphite crucible *C*, and slag in the lower graphite crucible *D*. The upper crucible is provided with a graphite stopper *B*, which can be manipulated by the sighting tube *A*. The sighting tube is fitted with a magnetically operated shutter and sight glass. The sight glass can be removed and samples can be taken from the lower graphite crucible. Another opening is provided so that samples can also be taken from the upper crucible. The lower crucible is rotated against the paddle *E* to achieve active stirring by means of a drive shaft from an outside motor. The crucible is enclosed in a silica tube which is sealed off by the two water-cooled brass heads. Static and rotating seals are used to keep the system gas-tight.

The furnace section is connected to the blank volume section by means of Pyrex glass tubing. The blank volume section, Fig. 1, consists mainly of a series of glass volumes which can be included in the system so that the total volume of the system may be changed. The volumes are placed in a water bath to minimize temperature fluctuations. In the blank volume section the gas pipette used for calibrations and the connections that lead to a mechanical vacuum pump and to a tank of CO are included.

The pressure measuring section consists of a pressure transducer which is connected on one side to the system and on the other to a blank volume where a known pressure of gas can be maintained. The transducer is a bellows and electrical resistance strain gage combination which converts pressure differences into electrical potential differences. This potential difference is recorded by a Speedomax recorder.

The salient features of the design are: 1) the metal and slag are melted separately and can be brought together at the desired time; thus, uncertainties introduced by cold additions of slag or metal are eliminated, and a true *zero time* is achieved; 2) the system is gas-tight and the CO evolved is readily measured by the pressure increase in the system; 3) the pressure increase is recorded automatically; thus, a complete record of CO evolved during sulfur transfer is available; and 4) samples of the slag and metal can be taken at short intervals.

Experimental Procedure

One hundred g of the slag and 100 g of the sulfur-free metal of the required compositions are melted separately in the two crucibles. The choice of weights was to simplify later calculations but sample weights removed were actually taken into consideration. Melting was done under vacuum. The graphite crucibles evolve gas and, unless they are baked out, the gas evolved introduces an error in the CO evolution measurements. The system is filled with CO after the crucible has been baked out, which usually takes about 2 hr.

An optical pyrometer sighted through the sighting tube is used to adjust the temperature of the crucibles. The optical reading is checked with a Pt—Pt-10 pct Rh thermocouple, which is introduced into the lower graphite crucible through the sighting tube. Fe-S master alloy is added to the metal in the upper graphite crucible to bring it to the required sulfur content.

The system is then made gas-tight and the required number of blank volumes is included. A blank reading of the pressure change with time in the system is made. This should be low. Initial samples of slag and metal are now taken. With the pressure measuring section in operation, the graphite stopper *B* is unscrewed to allow the metal in the upper graphite crucible to drop into the slag. Pressure change in the system is automatically recorded by the recorder. Samples of the metal and slag are taken at definite intervals after removing the sight glass. The metal is sampled with a 7 mm Vycor tube fitted with an aspirator bulb. The slag samples are solidified on the end of a ¼ in. diam copper rod. The metal and slag samples are weighed, crushed, and prepared for analysis. The slag samples are treated with a hand magnet and, lastly, with an isodynamic separator to remove metallic iron.

The runs were made at an initial pressure of 1 atm CO and the pressure increase did not exceed one tenth of an atmosphere. Judicious use of the blank volume keeps the pressure increase in the system low. Furthermore, since the system is open to the atmosphere during sampling, a large increase in pressure in the system is avoided.

From the pressure readings, the amount of CO evolved can be calculated, using the proper calibration factor. The calibration factor for the system was found from the pressure increase resulting from the addition of a known volume of gas to the system, using the gas pipette, Fig. 1.

Results

Rate studies have been made with measurement of CO evolution and concurrent analysis of slag for sulfur and combined iron, and of metal for sulfur

and alloying elements such as silicon and aluminum. Earlier measurements[7] showed that mechanical stirring increased the rate of sulfur transfer, but the primary object was to ensure representative sampling procedures. The known effects of varying the slag basicity and temperature have been included to provide comparison with other investigations.

In the early experiments attempts were made to use slag and metal compositions in equilibrium with respect to silicon. These runs involved a slag in the $CaO-Al_2O_3-SiO_2$ system and a metal containing sulfur (initially about 1 pct) and the equilibrium silicon content according to the data of Fulton and Chipman.[10] It was found that correlation between the amount of sulfur transferred to the slag and the amount of CO evolved was not exact, especially in the initial stages. The amount of CO evolved was always less, on an equivalent basis, than the amount of sulfur transferred. Accordingly, further experiments have involved chemical analyses for other elements which might take part in the reaction.

In Figs. 3a and 4a* the results of runs S-12 and K-10 are plotted, with the silicon content of the metal close to equilibrium with silica in the slag, according to Fulton and Chipman.[10] The figures show the variation with time of the sulfur and iron (plotted as FeO to emphasize that this is combined iron) contents of the slag, and the sulfur and silicon contents of the metal. Slag sulfur analyses were often unsatisfactory, largely, as is discussed later, because of lack of a suitable standard slag. The gas evolved did not contain any sulfur, within the limits of error in gas analysis, nor was there evidence of sulfur deposition within the apparatus. It may be assumed, therefore, that the sulfur lost from the metal is contained in the slag. The figures include the sulfur content of the slag as calculated from the metal analysis. Fig. 3a shows the worst disagreement experienced in any run between slag and metal sulfur analyses. Normally, agreement was much better than this, as is apparent in other figures.

* The relevant data on slag composition, temperature, etc. appear on the figures and are generally not given in the text.

It is evident from Fig. 3a that in run S-12 the silicon content of the metal is falling quite rapidly to the estimated equilibrium value while sulfur transfer is occurring. Fig. 4a shows, however, that the silicon content of the metal can decrease initially even though the starting silicon content is below the equilibrium value. In both cases iron is transferred to the slag in the initial stages, but the FeO content decreases again before sulfur transfer is quite completed.

The relationship between the various transfers is shown in Figs. 3b and 4b; CO evolution is also shown in these diagrams. The quantity plotted is the number of chemical equivalents of sulfur, iron, or silicon transferred to the slag, or the number of equivalents of CO evolved. It is evident that the sum of the equivalents of iron, silicon, and CO corresponds very closely at all times with the equivalents of sulfur transferred to the slag. An exact correspondence is not expected in view of the experimental and analytical errors discussed later.

Fig. 5 depicts the results for run K-8, in which the slag composition is the same as that in runs S-12 and K-10, Figs. 3 and 4; the initial silicon content is again fairly close to equilibrium. Precisely the same type of stoichiometric relation as in Figs. 3b and 4b is shown in Fig. 5b. Incidentally, the slightly

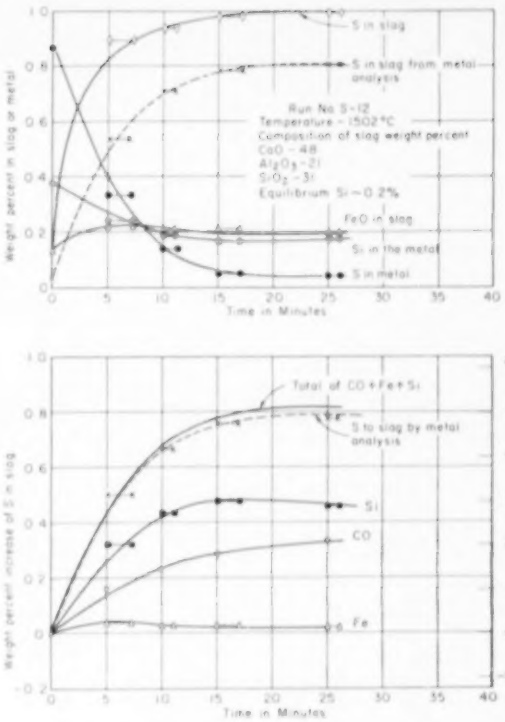


Fig. 3—Sulfur, iron, and silicon transfer and CO evolution in Run No. S-12. Initial metal silicon content slightly above lime, alumina, silica slag equilibrium. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

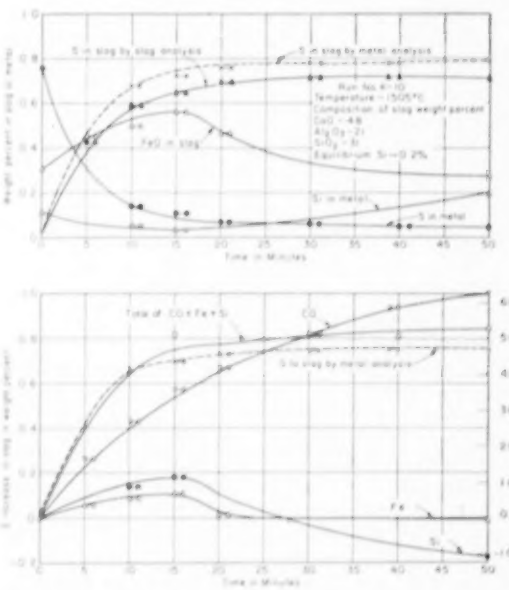


Fig. 4—Sulfur, iron, and silicon transfer and CO evolution in Run No. K-10. Initial metal silicon content slightly below lime, alumina, silica slag equilibrium. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

higher initial silicon and sulfur contents of the metal in run K-8, Fig. 5, make for faster desulfurization as compared with run K-10, Fig. 4. In run S-12, Fig. 3, the silicon content is still higher and results in still faster sulfur transfer. This is in agreement with previous work.[5, 6] It may be noted that the amount of iron transferred to the slag is less when the initial silicon content is higher and CO evolution is decreased considerably.

These features are better shown by a run in which the initial metal silicon content is much higher. Fig. 6 shows the results of run S-17 with initial metal silicon content of 12.7 pct. The temperature is higher than in previous runs so that the equilibrium silicon content of the metal is about 9 pct. Sulfur transfer is much faster than in any of the previous runs, the process being completed in 5 min. Iron transfer is from slag to metal, though the effect is almost negligible. CO evolution is much smaller than in the low silicon runs. The stoichiometric relations are much less satisfactory in Fig. 6b, largely because of the inaccuracy of silicon analysis. The spread in the silicon analysis indicated on Fig. 6a shows that precise correlation is not possible.

Fig. 7 shows results of a run with a fairly acid slag. A striking feature is that, in the initial stages of sulfur transfer, silicon is also transferred to the slag, though the equilibrium silicon content (about 12 pct) is much higher than the initial metal content (1.65 pct). In agreement with previous work,[5, 6] sulfur transfer is slower.

It seemed desirable to study the reaction in a silicon-free system. Figs. 8, 9, and 10 show the results of runs S-14, S-26, and S-27, respectively, in which lime-alumina slags were used; in two cases the metal did contain a little silicon. The effect of varying slag basicity is obscured by the different temperatures used. However, it is again evident that the sum of the equivalent transfers of iron and silicon and CO evolution equals the transfer of sulfur.

Fig. 11 is the plot of results from a run in which the same slag as in run S-14, Fig. 8, was used, but with the metal initially containing aluminum. Sulfur transfer is considerably accelerated by aluminum, as Goldman, Derge, and Philbrook[4] have established, but the stoichiometric relations in Fig. 11b are similar to those shown in Figs. 3 to 10. CO evolution is considerably less than in run S-14, Fig. 8, and iron transfer is also smaller.

Sources of Experimental Error—The final analysis of the sulfur transfer reaction depends on numerous measurements which are subject to error. The errors in each of these measurements are compounded in the final analysis of the experiments. The relevant errors arise in 1) chemical analysis, 2) sampling, 3) measurement of the evolved CO, 4) estimation of the relative weights of slag and metal, and 5) measurement of temperature and temperature variations in the crucible.

The chemical analysis errors are usually within ±1 pct of the reported analysis, except for low contents of iron oxide in the slag or very low alloy contents in the metal. However, the relative importance of the errors in analysis of each of the constituents is different, as may be seen from the stoichiometry of the reactions. This error is not appreciable when alloy contents are low, but when initial alloy contents are high, an error of ±1 pct becomes large enough to obscure the results. For instance, when the silicon is at a level of 10 pct, the uncertainty in the analysis is 0.2 pct Si, which is equivalent to an uncertainty of 0.46 g S. Since a total sulfur transfer of the order of 1 g is being considered, this error is large enough to make the results of run S-17 uncertain. Some difficulty was encountered with slag sulfur analysis, since standard slags of similar composition were not available for comparison.

The usual sampling errors are difficult to estimate. Furthermore, the efficiency of removal of metallic iron from slag samples cannot be checked, since there is no foolproof analytical method of differentiating between metallic iron found in the slag and the iron which is found combined in the slag.

The errors in CO evolution can be estimated from the check on the calibration system. This check is within 3 pct. The major error here is due to the blank, since the pressure measuring device is accurate to within ±0.1 pct.

The other errors that should be considered are in estimating the relative weights of metal and slag and temperature measurement. The temperature of the crucible is checked with a Pt—Pt-10 pct Rh thermocouple, and is expected to be within ±5°C.

The errors are many and agreement within ±15 pct for the data plotted in Figs. 3b to 11b should be considered reasonable.

Discussion

The most important conclusion to be drawn from these results is that, while the reaction is proceeding, CO evolution is not equivalent to sulfur transfer. Therefore, the reaction

$$\underline{S} + C + O^{=} = S^{=} + CO$$

does not express the stoichiometry of sulfur transfer. This is especially apparent when the iron contains silicon or aluminum.

In fact, the results show that the rate of sulfur transfer is equivalent to the sum of the rates of transfer of silicon, aluminum (when present), and iron, and the rate of CO evolution. If $\dot{n}$ represents rate of transfer or evolution in mol per sec, the positive sign being used for metal to slag transfer,

$$2\,\dot{n}_{s} = 2\,\dot{n}_{Fe} + 4\,\dot{n}_{Si} + 3\,\dot{n}_{Al} + 2\,\dot{n}_{CO}.$$

This stoichiometry is observed whether silicon is transferred from metal to slag or slag to metal, the correct sign being inserted in the equation above. It should be noted that, as the reaction proceeds, iron transfer takes place in the opposite direction from that found initially. The same phenomenon has been observed for silicon.

These observations are more readily understood if sulfur transfer from the metallic phase to the ionic phase is considered as an electrochemical partial reaction

$$\underline{S} + 2e^{-} = S^{=}.$$

To preserve electroneutrality and to correspond with the experimental observations, some or all of the following partial reactions must proceed concurrently.

$$\underline{Fe} = Fe^{++} + 2e^{-}$$
$$\underline{Si} = Si^{4+} + 4e^{-}$$
$$\underline{Al} = Al^{3+} + 3e^{-}.$$

In addition, electrons are furnished by reaction of oxygen ions with carbon to give CO, but the relevant

reaction is less readily defined. Three possibilities may be recognized.

1) CO may be formed by discharge of oxygen ions at the slag-metal interface according to the reaction

$$O^{--} + \underline{C} = CO + 2e^{-}.$$

2) Oxygen ions may react with graphite to form CO,

$$O^{--} + C_{(graphite)} = CO + 2e^{-}$$

and the electrons may pass through the metal to the slag-metal interface. This mechanism is analogous to the local cell action in corrosion where the anodic and cathodic reactions have different sites.

3) Oxygen may be transferred from slag to metal,

$$O^{--} = \underline{O} + 2e^{-}$$

and subsequently the reaction

$$\underline{C} + \underline{O} = CO$$

may take place in the bulk metal. A later examination of the data shows that this reaction plays only a minor part.

The basis for plotting element transfers in terms of equivalents in the b portions of Figs. 3 to 11 may now be appreciated. Preservation of electroneutrality demands that the transfer of 1 mol of the electronegative element, sulfur, from metal to slag be accompanied by the evolution of 1 mol CO or the transfer of 1 mol Fe, ½ mol Si, or 2/3 mol Al to the slag. In fact, there is no case where a simple equivalence between sulfur and any other single element is observed. All the element transfers that may occur do in fact take place. Addition of excess silicon or aluminum to the metal does not result in complete replacement of CO evolution by silicon or aluminum transfer, though CO evolution is decreased considerably. It is also obvious that in no case is iron transfer equivalent to sulfur transfer. Since CO is evolved from the beginning, such an equivalence could not be expected. In this respect the present results do not agree with those of Derge, Philbrook, and Goldman.[3] In line with the work of Goldman, Derge, and Philbrook,[4] it is expected that manganese in the metal would also take part in the reaction in a manner similar to that of iron. Attempts to duplicate some of the runs have shown that the individual element transfers do not remain exactly the same. For example, a little less CO may be evolved, but this is compensated for by the transfer of more iron or silicon to the slag.

It is evident from the data that there is no single step in the overall reaction of sulfur transfer with a rate sufficiently slower than those of other steps to be regarded as controlling the overall rate. Both CO evolution and transfer of electropositive elements occur regardless of the experimental conditions used here. For this reason it would be unprofitable to make deductions regarding the mechanism of the reaction from experiments in which sulfur transfer alone is measured. Similarly, measurements of the rate of CO evolution alone cannot be taken as quantitative indication of the rate of sulfur transfer, as runs S-15 and S-17 indicate.

The overall reaction appears to be of the first order with respect to transfer of sulfur from metal to slag. This is shown in Figs. 12 and 13, in which the logarithm of the sulfur content of the metal plotted against time gives a straight line, within the limits of accuracy, for the early stages of the reaction. The slope of such a line gives the specific reaction rate. This slope is higher for runs in which

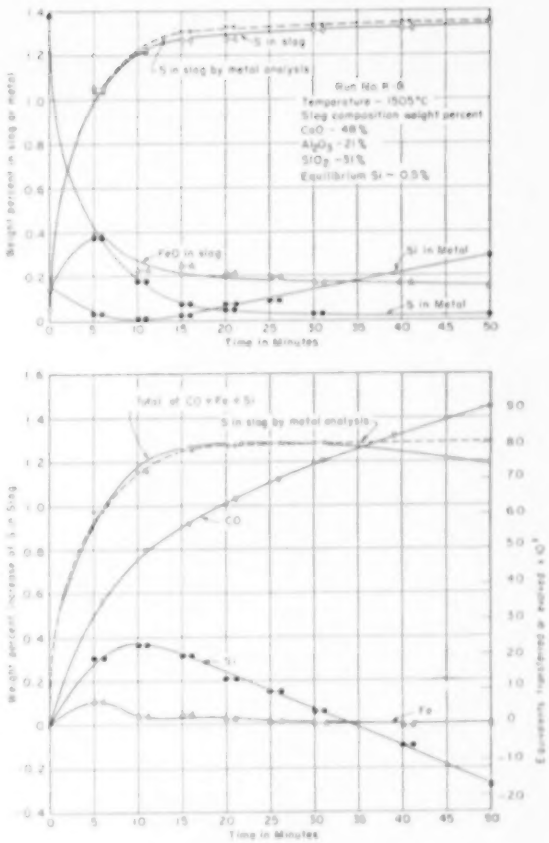


Fig. 5—Sulfur, iron, and silicon transfer and CO evolution in Run No. K-8. Initial metal silicon content slightly below lime, alumina, silica slag equilibrium. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

appreciable amounts of silicon and aluminum are present in the metal.

Interpretation of the apparent first order is uncertain since several mechanisms are consistent with such a result, and the complexity of the reaction has already been demonstrated. It is possible, however, to clarify the mechanism by considering the rates of simultaneous reactions, such as sulfur transfer, iron transfer, and CO evolution in conjunction with available equilibrium data. It will be shown that some mechanisms considered in the past are incompatible with the present observations. In the treatment which follows, a process of elimination of other possibilities reveals that an electrochemical mechanism most likely accounts for the experimental observations. The treatment is based on the *two-film* hypothesis of reactions between two liquid phases developed by Whitman and co-workers,[13-16] and further considered by Gordon and Sherwood.[17]

Since the reactions involve transfer across the slag-metal interface, transport of reactants to and from this interface must be considered. The system is stirred, but the conditions of convection are unknown. However, the bulk concentrations may be regarded as uniform and the actual concentration profiles at the interface may be replaced by stationary boundary layers or films across which the variation of concentration with distance from the interface is linear. These layers have *effective thick-*

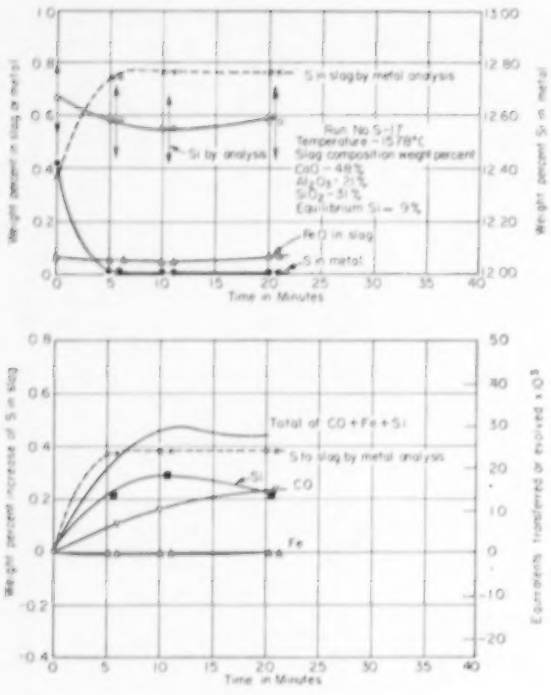


Fig. 6—Sulfur, iron, and silicon transfer and CO evolution in Run No. S-17. Initial metal silicon content well above lime, alumina, silica slag equilibrium. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

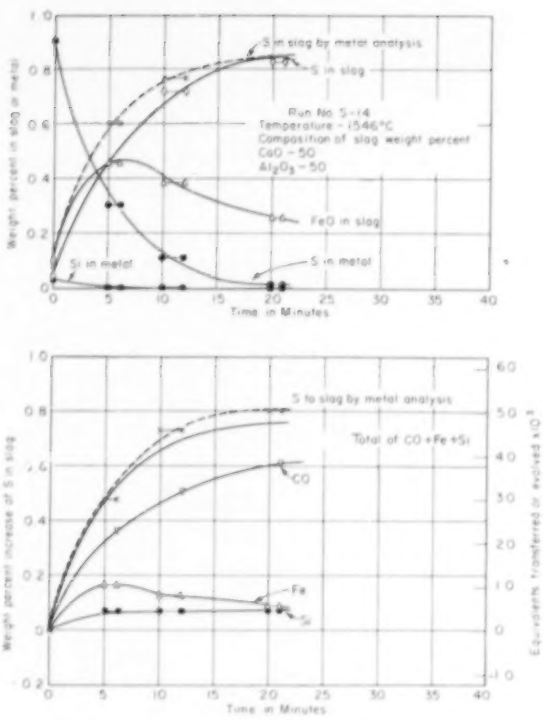


Fig. 8—Sulfur, iron, and silicon transfer and CO evolution in Run No. S-14; 50 pct CaO, 50 pct Al_2O_3 slag. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

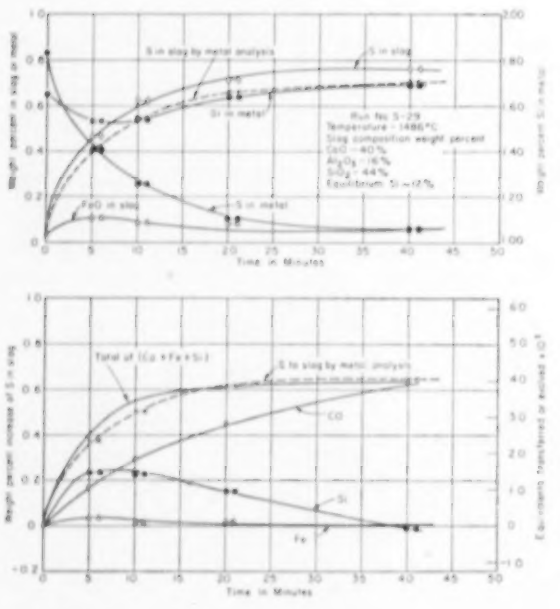


Fig. 7—Sulfur, iron, and silicon transfer and CO evolution in Run No. S-29. Initial metal silicon content well below lime, alumina, silica slag equilibrium. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

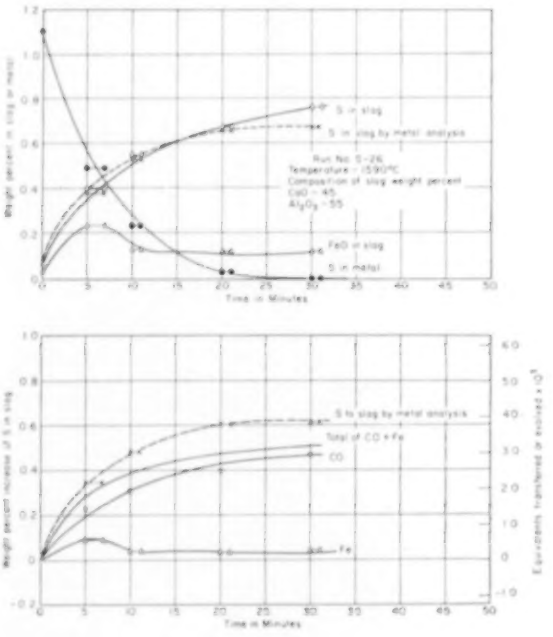


Fig. 9—Sulfur and iron transfer and CO evolution in Run No. S-26; 45 pct CaO, 55 pct Al_2O_3 slag. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

nesses across which transport of reactants is supposed to occur by diffusion.

The authors are indebted to C. Wagner for the following application of the hypothesis to sulfur transfer. Concentrations of elements in both metal and slag are in terms of gram moles per cubic centimeter in accordance with usual practice in treatment of diffusion. The symbols used, similar to those employed by Whitman et al., and suggested by Wagner, are $\dot{n}_i$, rate of transfer of i from metal to slag, mol per sec; D'_i, diffusion coefficient of i in metal; D''_i, diffusion coefficient of i in slag; δ'_i, effective boundary layer thickness for element i in the metal; δ''_i, effective boundary layer thickness for element i in the slag; C'_i, concentration of i in bulk metal, mol per cu cm; C''_i, concentration of i in bulk slag, mol per cu cm; $C'_i{}^*$, concentration of i in metal at the interface, mol per cu cm; $C''_i{}^*$, concentration of i in slag at the interface, mol per cu cm; and A, nominal area of slag/metal interface.

For simplicity those results will be considered which are obtained from runs in which sulfur was transferred from iron free of silicon and aluminum and the slag contained only lime and alumina. The stoichiometric plots show that

$$2\,\dot{n}_s = 2\,\dot{n}_{Fe} + 2\,\dot{n}_{Si}\,.$$

To formulate expressions for transfer rates some mechanism for CO evolution must be assumed. In the first place it will be shown that if CO is assumed to be evolved according to the reaction in the bulk metal

$$C + O = CO$$

the rate of evolution should be quite small, since the maximum possible rate of oxygen transfer from slag to metal is small compared with the rate of sulfur transfer from metal to slag. (Actually the rate of CO evolution is comparable to the rate of sulfur transfer, so that the assumed mechanism cannot be correct.)

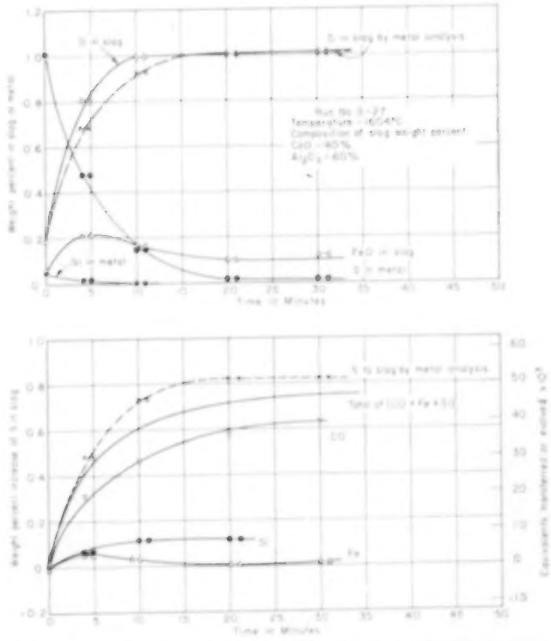


Fig. 10—Sulfur, iron, and silicon transfer and CO evolution in Run No. 5-27; 40 pct CaO, 60 pct Al_2O_3 slag. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

According to the assumed mechanism, the rate of CO evolution cannot be higher than the rate of transfer of oxygen to the bulk metal. Transport of oxygen ions in the slag need not be considered in view of the high concentration, so the rate of oxygen transfer may be expressed as follows

$$\frac{\dot{n}_o}{A} = -\frac{D'_o}{\delta'_o}\,(C'_o{}^* - C'_o)\,. \qquad [1]$$

Transfer of iron and sulfur are similarly expressed; transport of iron in the metal, as with oxygen in the slag, is not important.

$$\frac{\dot{n}_s}{A} = \frac{D'_s}{\delta'_s}\,(C'_s - C'_s{}^*) = \frac{D''_s}{\delta''_s}\,(C''_s{}^* - C''_s)\,. \qquad [2]$$

$$\frac{\dot{n}_{Fe}}{A} = \frac{D''_{Fe}}{\delta''_{Fe}}\,(C''_{Fe}{}^* - C''_{Fe})\,. \qquad [3]$$

To maintain electroneutrality the following relation must hold, remembering that a positive value for $\dot{n}$ means transfer from metal to slag

$$2\,\dot{n}_{Fe} = 2\,\dot{n}_s + 2\,\dot{n}_o\,. \qquad [4]$$

The most favorable conditions for CO evolution occur when oxygen transfer is at its maximum rate. This will be when $C'_o{}^*$ is the equilibrium value in reactions taking place at the interface. The following reactions are therefore assumed to be at equilibrium

$$S + O^{--} = S^{--} + O$$

$$K_s = \frac{C''_s{}^* \cdot C'_o{}^*}{C'_s{}^* \cdot C''_o{}^*}\,. \qquad [5]$$

$$Fe + O = Fe^{++} + O^{--}$$

$$K_s = \frac{C''_{Fe}{}^* \cdot C''_o{}^*}{C'_{Fe}{}^* \cdot C'_o{}^*}\,. \qquad [6]$$

In addition, since the bulk metal is saturated with carbon and it is assumed that CO evolution does not take place at the interface, the following reaction can be written

$$C_{(graphite)} + O = CO$$

$$K_c = \frac{p_{CO}}{C'_o} \qquad [7]$$

The use of concentrations instead of activities may be justified, since only an order of magnitude solution is desired. For the same reason values of D/δ will be taken as the same in every case. Although the value is actually different for each element, there is compensation in the fact that δ is larger for those elements with higher values of D.

The equations involve seven unknowns in $\dot{n}$, and $C'_i{}^*$ and seven conditions in Eqs. 1 through 4 and the three equilibrium constants, so that a solution is possible. In practice C'_o is not measured, so that only the initial stages of the reaction when $C'_o \simeq 0$ may be considered. It should be noted that this also gives the maximum rate of oxygen transport. Substituting Eqs. 1, 2, and 3 in Eq. 4, we obtain

$$(C''_{Fe}{}^* - C''_{Fe}) = (C'_s - C'_s{}^*) - (C'_o{}^* - C'_o)$$
$$= (C''_s{}^* - C''_s) - (C'_o{}^* - C'_o)\,. \qquad [8]$$

In the initial stages C'_o, C''_s, and C''_{Fe} may be set equal to zero, so Eq. 8 becomes

$$C''_{Fe}{}^* = C''_s{}^* - C'_o{}^* = (C'_s - C'_s{}^*) - C'_o{}^*\,. \qquad [9]$$

However, the treatment is simpler if it is as-

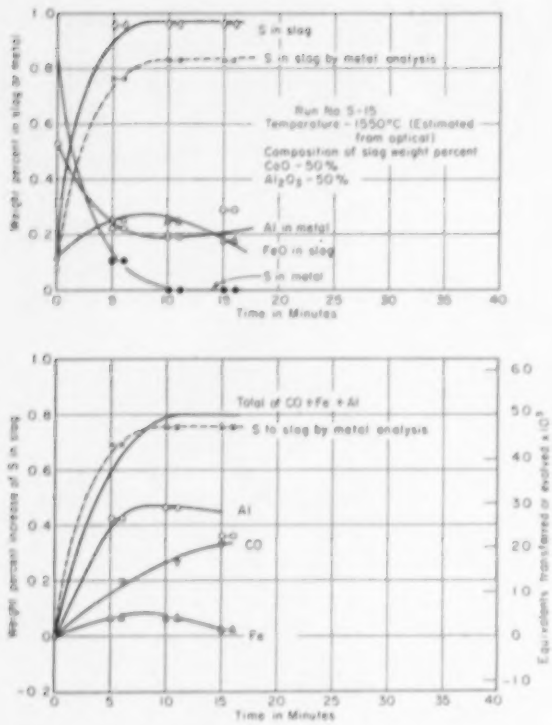


Fig. 11—Sulfur and iron transfer and CO evolution in Run No. S-15; 50 pct CaO, 50 pct Al_2O_3 slag. Initial aluminum content of metal was 0.53 pct. a, TOP, analyses in weight percent; and b, BOTTOM, chemical equivalents.

sumed that the rate of oxygen transfer is negligible compared to that of sulfur and iron. This asumption will be shown to be consistent in what follows. Eq. 4 would then become

$$2\,\dot{n}_{F_o} = 2\,\dot{n}_s \qquad [10]$$

and substituting Eqs. 2 and 3 in Eq. 10, we have, considering again only the initial stages of the reaction

$$C''_{F_o}{}^{\circ} = C''_s{}^{\circ} = C'_s - C'_s{}^{\circ}. \qquad [11]$$

Combining Eqs. 5 and 6 and using Eq. 11

$$K_sK_s = \frac{(C''_s{}^{\circ})^2}{C'_{F_o}{}^{\circ} \cdot C'_s{}^{\circ}} = \frac{(C''_s{}^{\circ})^2}{C'_{F_o}{}^{\circ}\,(C'_s - C''_s{}^{\circ})} \qquad [12]$$

or

$$(C''_s{}^{\circ})^2 + K_sK_s\,C'_{F_o}{}^{\circ} \cdot C''_s{}^{\circ} - K_sK_sC'_{F_o}{}^{\circ}C'_s = 0. \qquad [13]$$

This is a quadratic in $C''_s{}^{\circ}$, since $C'_{F_o}{}^{\circ}$ and C'_s are known. K_sK_s may now be estimated.

From the data of Rocca, Grant, and Chipman,[35] with concentrations in weight percentage

$$K'_sK'_s = \frac{\%\ Fe^{++} \cdot \%\ S^{--}}{\%\ Fe \cdot \%\ \underline{S}} \sim 0.03 \qquad [14]$$

but wt pct $i = C_iM_i\ 100/\rho$, where M_i is molecular weight of i and ρ is the density of slag or metal, equal to 3 and 7 g per cu cm, respectively. Hence, with concentrations in gram moles per cubic centimeter

$$K_sK_s = 5.5 \times 10^{-6}. \qquad [15]$$

Substituting Eq. 15 in Eq. 13 and taking $C'_{F_o}{}^{\circ} \cong C'_{F_o} = 0.12$ mol per cu cm, and $C'_s = 2.2 \times 10^{-4}$ mol per cu cm (corresponding to 1 pct S, which is the initial S content), solution for $C''_s{}^{\circ}$ gives

$$C''_s{}^{\circ} = 10^{-6}\ \text{mol per cu cm} = C''_{F_o}{}^{\circ}. \qquad [16]$$

The oxygen content at the interface, $C'_o{}^{\circ}$, may be calculated, using Eqs. 6 and 16.

K'_s may be estimated from data given by Rocca, Grant, and Chipman[35] for slags which do not contain more than 12 pct FeO. A check may be obtained from the data of Bishop.[36]

$$K'_s = \frac{\%\ Fe^{++} \cdot \%\ O^{--}}{\%\ Fe \cdot \%\ \underline{O}} \sim 50. \qquad [17]$$

From Eq. 16 and converting to weight percentage

$$\%\ Fe^{++} = 10^{-6} \times 56 \times 100 \times 1/3 = 1.9.$$

Using this value and $\%\ O^{--} = 37.8$ for slag containing 50 pct CaO and 50 pct Al_2O_3, we obtain from Eq. 17

$$\%\ O = 0.014$$

$$C'_o{}^{\circ} = 0.014 \times 7 \times 100 \times 1/6 = 6.1 \times 10^{-4}\ \text{mol per cu cm.}$$

The ratio $\dot{n}_o/\dot{n}_s$ may now be calculated.

$$\frac{\dot{n}_o}{\dot{n}_s} = \frac{(C'_o{}^{\circ} - C'_o)}{(C''_s{}^{\circ} - C''_s)}$$

but the maximum values of $\dot{n}_o$ and $\dot{n}_s$ applying to the initial stages of the reaction will be used.

$$\frac{\dot{n}_o}{\dot{n}_s} = \frac{C'_o{}^{\circ}}{C''_s{}^{\circ}} = \frac{6.1 \times 10^{-4}}{1 \times 10^{-4}} = 0.061.$$

Successive approximations show that this result is valid. Hence, the initial assumption that oxygen

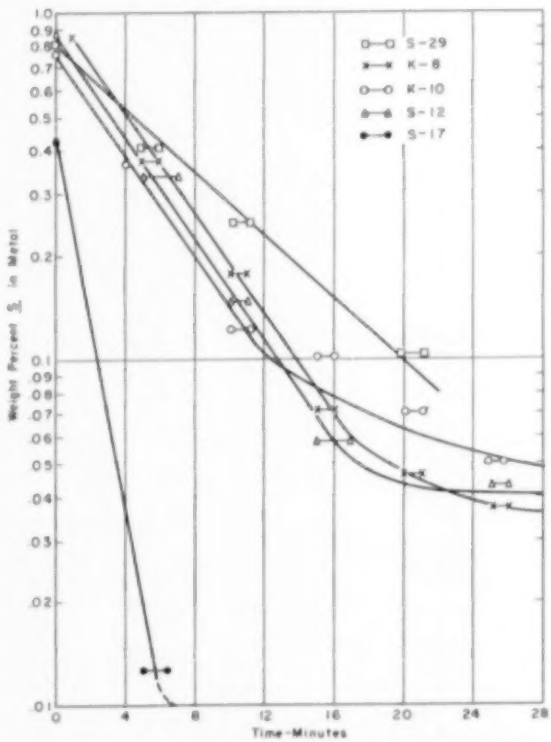


Fig. 12—Log wt pct S in metal vs time for CaO-Al_2O_3-SiO_2 slags.

transfer is negligible compared with sulfur and iron transfer, so that $\dot{n}_{Fe} \cong \dot{n}_{s}$, is justified.

However, the experimental results show that iron transfer is not equivalent to sulfur transfer. Considerable amounts of CO are evolved from the beginning. It must be concluded, therefore, that the assumption regarding the nature of the CO evolution reaction is incorrect and that the rate of transfer of oxygen to the metal does not determine the rate of CO evolution.

A similar calculation could, in principle, be made for those experimental results involving silicon transfer, since a new condition may be set for each unknown introduced.

An alternative mechanism for CO evolution may now be examined. CO may be formed by reaction between carbon and oxygen at the slag-metal interface; thus transfer of oxygen to the bulk metal is not necessary but carbon must be transferred from the bulk metal to the interface. The rate of CO evolution may then be expressed as follows

$$\frac{\dot{n}_{CO}}{A} = \frac{D'_C}{\delta'_C}(C'_C - C'_C{}^{*}). \qquad [18]$$

It is of interest to examine whether the reaction at the interface is at equilibrium. If so, this would imply that CO evolution was transport controlled. It should be noted that transport of carbon is not likely to control the rate of evolution, in view of the high carbon concentration, but the reaction does not take place independently of sulfur and iron transfer. For the reaction $\underline{C} + \underline{O} = CO$, the equilibrium constant is then

$$K_{18} = \frac{p_{CO}}{C'_C{}^{*} \cdot C'_O{}^{*}}. \qquad [19]$$

In view of the assumed mechanism for CO evolution, Eq. 4 no longer applies. Instead

$$\dot{n}_{Fe} + \dot{n}_{CO} = \dot{n}_{S}. \qquad [20]$$

From Eqs. 6 and 19

$$\frac{p_{CO} \cdot C'_{Fe}{}^{*}}{C''_O{}^{*} \cdot C''_{Fe}{}^{*} \cdot C'_C{}^{*}} = \frac{K_{18}}{K_4} = K_{21}. \qquad [21]$$

This corresponds to the reaction

$$\underline{C} + O^{=} + Fe'' = CO + Fe.$$

$C'_C{}^{*}$ is not known but it may be assumed that it is not very different from the bulk concentration. The equilibrium may then be written

$$C_{(graphite)} + O^{=} + Fe'' = CO + Fe.$$

The iron oxide content of a slag in equilibrium with graphite, iron, and CO at 1 atm is 0.03 pct, according to the data in *Basic Open Hearth Steelmaking*[11] and the results of Hatch and Chipman.[10]

However, the experimental results for those runs in which lime-alumina slags were used show that much higher FeO contents, 0.2 to 0.4 pct, are reached in the bulk slag. The concentration at the interface must be still higher, since iron is transferring from metal to slag in the initial stages. It is not conceivable that the assumption that $C'_C{}^{*} \cong C'_C$ is so seriously in error. Hence, it must be concluded that equilibrium in the assumed reaction is not reached, and CO evolution is not wholly transport controlled.

There is no particular reason for this to be the case for the reaction $\underline{C} + \underline{O} = CO$. Therefore, it would seem that this reaction, contrary to past suggestions, plays only a minor part in CO evolution.

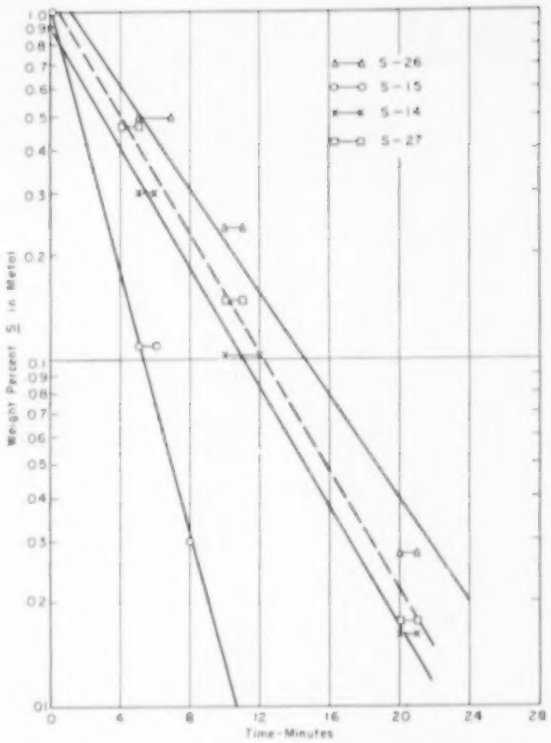


Fig. 13—Log wt pct S in metal vs time for CaO-Al_2O_3 slags.

Alternative mechanisms for CO evolution must involve reaction of carbon with oxygen ions in the slag. This reaction may occur according to the equation $\underline{C} + O^{=} + Fe'' = CO + Fe$, or according to one or both of the electrochemical mechanisms considered earlier. The latter may be divided into anodic and cathodic reactions. The cathodic reaction is $Fe'' + 2e^{-} = Fe$ and, if oxygen ions are discharged at the slag-metal interface, the anodic reaction is $\underline{C} + O^{=} = CO + 2e^{-}$. Oxygen ions may also be discharged at the slag-crucible interface, in which case the anodic reaction is $C_{(graphite)} + O^{=} = CO + 2e^{-}$. The *external circuit* is provided by the metal or crucible plus metal.

The present experiments cannot be used to decide whether the electrochemical mechanism plays an important part. If it does not, then the reaction involves the collision of carbon atoms with oxygen and iron ions at the same site on the interface and might therefore be considered termolecular. However, oxygen ions are present in considerable excess of iron ions, so that the reaction would almost certainly be of no higher than second order. It has already been shown that this reaction is not at equilibrium, but the reason for this is not obvious at present. If the mechanism is electrochemical, it would seem likely that the anodic discharge of oxygen ions is a slow step.

A feature of the electrochemical mechanism is that a potential difference should exist between cathodic and anodic sites which, in part, determines the rate of CO evolution. This could be measured under experimental conditions different from those used here. Further work is necessary to ascertain the part played by the electrochemical mechanism and suitable experiments are presently being conducted.

Summary and Conclusions

1) The transfer of sulfur from carbon-saturated iron to oxide slags may occur by an electrochemical mechanism.

2) Sulfur transfer from metal to slag is accompanied by transfer of electropositive elements, such as iron, silicon, and aluminum, and evolution of CO.

3) The stoichiometric relations among the various element transfers are those to be expected from the system remaining electrically neutral.

4) The reaction $C + O = CO$ does not occur to any important extent during sulfur transfer. Instead, CO evolution occurs by discharge of oxygen ions at the slag-metal interface or by *local cell action* when a graphite crucible is used.

5) Of the various *side reactions* noted as occurring during sulfur transfer none exerts a predominant influence, to the exclusion of others, on the extent of the overall reaction.

Acknowledgments

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References

[1] L. C. Chang and K. M. Goldman: Kinetics of Transfer of Sulfur Across a Slag-Metal Interface. *AIME Trans.*, 1948, vol. 176, p. 309.

[2] G. Derge, W. O. Philbrook, and K. M. Goldman: The Mechanism of Sulphur Transfer Between Carbon Saturated Iron and $CaO-SiO_2-Al_2O_3$ Slags. *AIME Trans.*, 1950, vol. 188, p. 1111; JOURNAL OF METALS, September 1950.

[3] N. J. Grant, O. Tnoli, and J. Chipman: Effect of Silica Reduction on the Desulphurizing Power of Blast Furnace Slags. *AIME Trans.*, 1951, vol. 191, p. 672; JOURNAL OF METALS, August 1951.

[4] N. J. Grant, U. Kalling, and J. Chipman: Effect of Manganese and Its Oxide on Desulphurization by Blast Furnace Type Slags. *AIME Trans.*, 1951, vol. 191, p. 666; JOURNAL OF METALS, August 1951.

[5] N. J. Grant, J. W. Dowding, and P. J. Murphy: Manganese as an Indicator of Blast Furnace Slag Oxidation and Desulfurizing Power. *AIME Trans.*, 1953, vol. 197, p. 1451; JOURNAL OF METALS, November 1953.

[6] K. M. Goldman, G. Derge, and W. O. Philbrook: Effect of Si, Mn, P, Al, C, Ni, and Cu on the Mechanism of Sulphur Transfer Across a Slag-Metal Interface. *AIME Trans.*, 1954, vol. 200, p. 534; JOURNAL OF METALS, May 1954.

[7] E. T. Turkdogan, R. A. Hancock, and J. Pearson: Desulphurization of Carbon Saturated Iron: Influence of Silicon, Manganese, and Aluminum. *Journal* Iron and Steel Inst., 1955, vol. 179, p. 338.

[8] P. Kozakevitch, G. Urbain, and M. Sage: Sur La Tension Interfaciale De Fonte/Laitier et Le Mechanisme De Disulfuration. *Revue de Metallurgie*, 1955, vol. 52, p. 191.

[9] S. Ramachandran, T. B. King, and N. J. Grant: The Rate of Sulfur Transfer Between Blast Furnace Type Metal and Slag. *Proceedings* AIME Blast Furnace Conference, April 1955.

[10] J. C. Fulton and J. Chipman: Slag-Metal-Graphite Reactions and the Activity of Silica in Lime-Alumina-Silica Slags. *AIME Trans.*, 1954, vol. 200, p. 1136; JOURNAL OF METALS, October 1954.

[11] W. G. Whitman: *Chemical & Metallurgical Engineering*, 1923, vol. 29, No. 4, p. 146.

[12] W. G. Whitman and D. S. Davis: *Industrial and Engineering Chemistry*, 1924, vol. 16, p. 1233.

[13] W. K. Lewis and W. G. Whitman: *Industrial and Engineering Chemistry*, 1924, vol. 16, p. 1215.

[14] K. G. Gordon and T. R. Sherwood: *Chemical Engineering Progress*, Symposium Series No. 10, 1954, p. 15.

[15] R. Rocca, N. J. Grant, and J. Chipman: Distribution of Sulfur Between Liquid Metals and Slags of Low Iron Oxide Concentration. *AIME Trans.*, 1951, vol. 191, p. 319; JOURNAL OF METALS, April 1951.

[16] H. Bishop: Sc.D. Thesis, Massachusetts Institute of Technology, 1955.

[17] *Basic Open Hearth Steelmaking*. New York, AIME, 1951.

[18] G. G. Hatch and J. Chipman: Sulfur Equilibria Between Iron Blast Furnace Slags and Metals. *AIME Trans.*, 1949, vol. 185, p. 274; JOURNAL OF METALS, April 1949.

Discussion of this paper sent (2 copies) to AIME by Jan. 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957, and in JOURNAL OF METALS, October 1957.

Equilibria in Reactions of Hydrogen, and Carbon Monoxide With Dissolved Oxygen in Liquid Iron; Equilibrium in Reduction of Ferrous Oxide With Hydrogen, and Solubility of Oxygen in Liquid Iron

Equilibria in the following reactions have been investigated in the range of 1550° to 1700°C: 1) $H_2 + \underline{O}$ (in liquid Fe) $= H_2O$, 2) $CO + \underline{O}$ (in liquid Fe) $= CO_2$, and 3) $H_2 + Fe_xO$ (liquid wüstite) $= H_2O + xFe$ (liquid). Solubility of oxygen in liquid iron is obtained indirectly with a high degree of accuracy from the equilibrium data on reactions 1 and 3. The results are expressed in thermodynamic functions, and correlated with new data on the standard free energies of H_2, H_2O, O_2, CO, and CO_2.

by Nev A. Gokcen

DISCREPANCIES and scattering in the equilibrium data on the reactions of hydrogen, and CO with dissolved oxygen in liquid iron are unduly large. Available experimental results on the reduction of liquid ferrous oxide, i.e., wüstite, with hydrogen and CO are questionable, as pointed out by Darken and Gurry.[1] Direct determinations of the solubility of oxygen in liquid iron are subject to errors which cannot be easily reduced by further experimental refinements, and therefore an accurate but indirect method is highly desirable. The purpose of this investigation was, therefore, 1)

N. A. GOKCEN, Member AIME, formerly associated with Michigan College of Mining and Technology, Houghton, Mich., is Associate Professor of Metallurgy, University of Pennsylvania, Philadelphia.

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to determine equilibria in the following reactions from 1550° to 1700°C

$$H_2 + \underline{O} = H_2O \qquad K_1 = \frac{P_{H_2O}}{P_{H_2} \times \%\,\underline{O}} \qquad [1]$$

$$CO + \underline{O} = CO_2 \qquad K_2 = \frac{P_{CO_2}}{P_{CO} \times \%\,\underline{O}} \qquad [2]$$

$$H_2 + Fe_xO \text{ (liquid wüstite)} = H_2O + xFe(l)$$
$$K_3 = \frac{P_{H_2O} \times N'_{Fe}}{P_{H_2} \times N_{Fe_xO}} \qquad [3]$$

where N_{Fe} and N_{Fe_xO} are the mol fractions of iron and wüstite and the symbols underlined represent dissolved elements in liquid iron in accord with the notation used in the *Basic Open Hearth Steelmaking*;[2] 2) to establish the solubility of oxygen accurately from the equilibrium data on reactions 1 and 3; and 3) to correlate the results by using recent thermodynamic data on H_2, H_2O, O_2, CO, and CO_2.

The paper consists of three parts, each dealing mainly with one of the preceding reactions.

Equilibrium in the Reaction $H_2 + O = H_2O$

Experimental Method—The experimental method used in this investigation consisted of equilibrating 6 to 12 g of liquid iron in alumina crucibles with gas mixtures of known composition. The metal, through which the gas was bubbled to insure intimate contact, was then quenched and analyzed for oxygen by the vacuum-fusion method.[3]

The apparatus used in this part consisted of a steam-hydrogen mixer and a furnace.

Steam-Hydrogen Mixer: The gas mixer for obtaining steam and hydrogen mixtures is of all glass construction, as shown in Fig. 1. Water-pumped hydrogen from a gas cylinder was passed through a tube containing platinized asbestos held at 400°C in order to convert a trace of oxygen into water vapor. A flow rate of 100 ml per min was controlled with a capillary-type flowmeter *C* and a bubbling column *B'*. The gas was then presaturated at *D* and led into a condenser system immersed in a thermostat controlled to within ±0.02°C. The temperature of the thermostat was measured with a thermometer certified by the Bureau of Standards. Any desired gas composition was obtained by adjusting the temperature of the thermostat. The presaturator *D* was heated sufficiently to avoid the condensation of an excessive amount of water as judged from the rate of flow out of the capillary tube *E*. The resulting mixture of H_2 and H_2O was then led to the furnace through the resistance-heated glass tubing *F* kept at 100°C in order to avoid condensation.

Dried argon was passed through pure magnesium chips held at 630°C in a stainless steel tube in order to remove any trace of oxygen and nitrogen. The gas was regulated by the flowmeter *A* and mixed with the moist hydrogen emerging from the thermostat. The ratio of argon to hydrogen was kept at 4.5 in all runs to prevent hydrogen porosity in the ingots.

Furnace: The design of the furnace is shown in Fig. 2. The furnace core was made with a very pure, dense, and impermeable beryllia tube, 1 in. ID, 1⅝ in. OD, and 26 in. long, over which a 22 gage Pt+10 pct Rh wire was wound differentially toward the center as follows:

Inches from end:	1	2	2	1	1¾
Turns:	8	14	12	5	7

Temperature gradient measurements indicated that

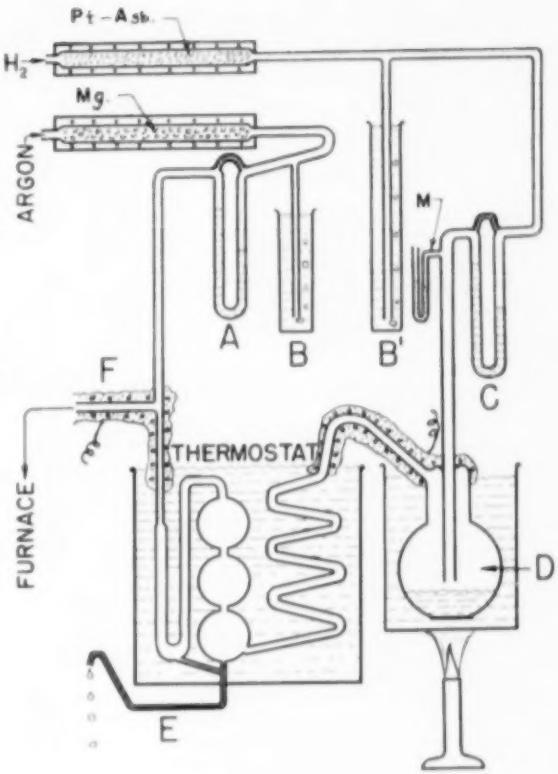

Fig. 1—Steam-hydrogen mixer.

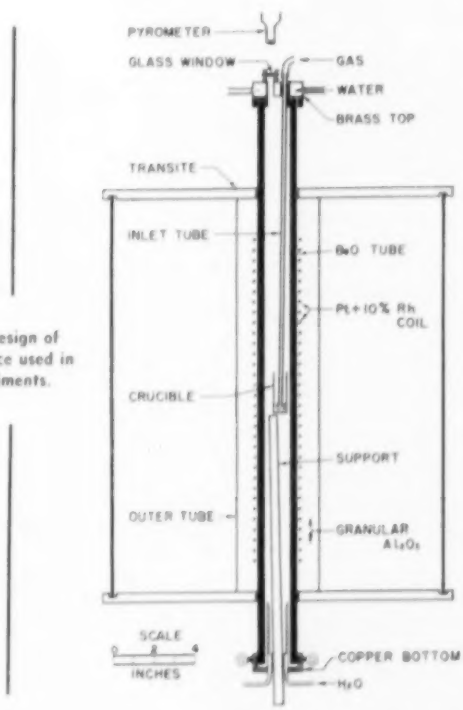

Fig. 2—Design of the furnace used in the experiments.

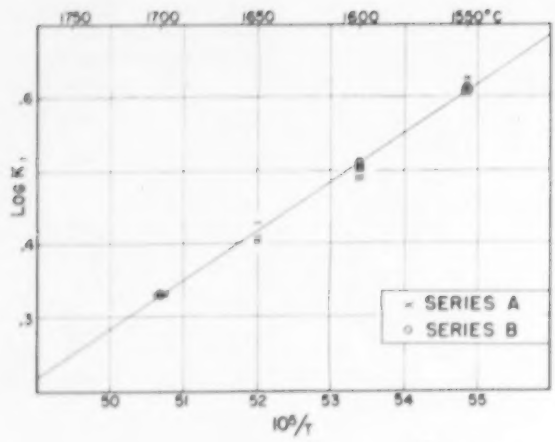

Fig. 3—Effect of temperature upon $K_1 = \frac{P_{H_2O}}{P_{H_2} \times \%O}$.

at least 3 in. of uniform temperature zone existed at 1500°C in the furnace tube.

The power for the furnace was obtained from an autotransformer (Variac) connected to 440 v. The temperature was accurately controlled by changing the power setting on the transformer.

The furnace tube was fitted with a brass top which was cooled with warm water to avoid condensation. A silicone rubber gasket assured a firm seal when the brass top was clamped on the refractory tube. A removable glass window permitted temperature measurements with an optical pyrometer. The inlet tube, 5/16 in. OD, ⅛ in. ID, and 17 in. long, and made of pure dense alumina* was tightly sealed into the brass top by means of a compression fitting and a silicone rubber ring. Connection between this tube and the gas system was made with a 1½ in. long heavy wall rubber tubing which was changed every week.

* All pure dense alumina refractories were of Norton Co. RA 7232 mixture containing at least 99.5 pct Al_2O_3.

A removable, water-cooled copper bottom provided a seat and a fast cooling medium for the crucible when the supporting rod was pulled out at the end of each run.

Temperature Measurements: Temperature was measured with a Leeds & Northrup optical pyrometer calibrated against the Pt—Pt-10 pct Rh thermocouple. Briefly, the calibration was made as follows: The furnace was arranged as shown in Fig. 2 except that the supporting rod was replaced with a pure alumina protection tube into which a standardized couple was inserted. Optical readings were taken by sighting on the visible tip of the tube when temperature fluctuation was negligibly small. Simultaneously, true temperature measurements were made with the thermocouple. The results in the range of 1300° to 1610°C yielded a correction of only 15° to 22°C. It was therefore concluded that the extrapolation of this correction to 1700°C would introduce a negligibly small error.

The optical pyrometer was also checked against the melting point of 99.96 pct pure Fe. Melting and freezing point determinations under argon containing 10 pct H_2 agreed within 3°C and averaged 1537°C.

The sight window was cleaned every day, though calibration without cleaning the window for three days showed that no film or dust interfered with temperature measurements.

The exact magnitude of errors in the optical temperature measurements was difficult to estimate. Repeated checks with thermocouples at various times indicated deviations less than 4° up to 1550°C. Therefore, it was believed safe to claim an accuracy of ±4° up to 1600° and ±6° at 1700°C.

Experimental Procedure—Each day the apparatus was prepared for an experimental run by replacing the inlet tube, cleaning the sight window, starting the purification trains and the thermostat, flushing the system, checking for leakage, and increasing the furnace temperature to the desired range. A pure dense alumina crucible ¾ in. OD, 1/20 in. wall, and 2¼ in. high was charged with 6 to 12 g of electrolytic iron of specially high purity (National Radiator Co. Grade A-104). The crucible was placed into the copper bottom which was inserted into and clamped on the furnace tube. A supporting rod was then inserted and the crucible was slowly pushed up into the thermal center of the furnace. After melting the charge, the liquid metal was pushed up further until the inlet tube was immersed approximately 2 mm as judged by the manometer *M* in Fig. 1. At this time gases purred uniformly through the melt, but when the immersion was excessive the pressure fluctuation was quite irregular. The current input was adjusted to obtain a constant temperature at which the metal was held at least 1 hr. A few runs held at constant temperature from 20 min to 2 hr indicated that equilibrium was reached within less than 20 min in accord with expectation discussed elsewhere.[4] At the end of each run the crucible was quickly lowered into the copper bottom and the supporting rod was removed. The melt froze and formed a sound ingot within 3 sec. The copper bottom was removed and the crucible was taken out and broken up to recover the ingot. Two samples for analysis were obtained by splitting the entire ingot horizontally or vertically with a hacksaw and then grinding at least 1/32 in. off the outer skin. The samples were then polished, degreased, and analyzed in a vacuum-fusion apparatus whose absolute accuracy was determined by a new method.[5]

Experimental Results—Experimental results are shown in Table I. Heats in series B were made in the beryllia furnace tube shown in Fig. 2, whereas those

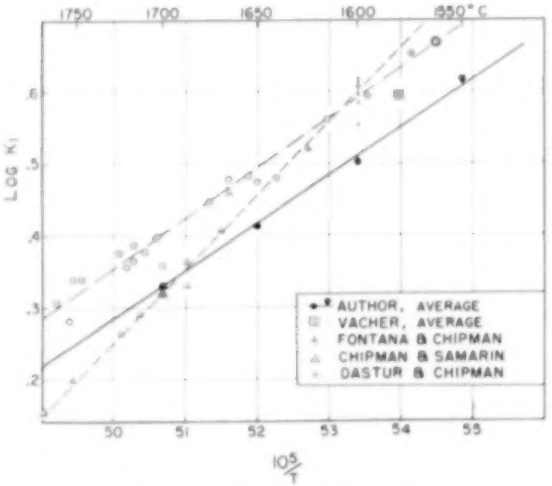

Fig. 4—Comparison with other data on K_1.

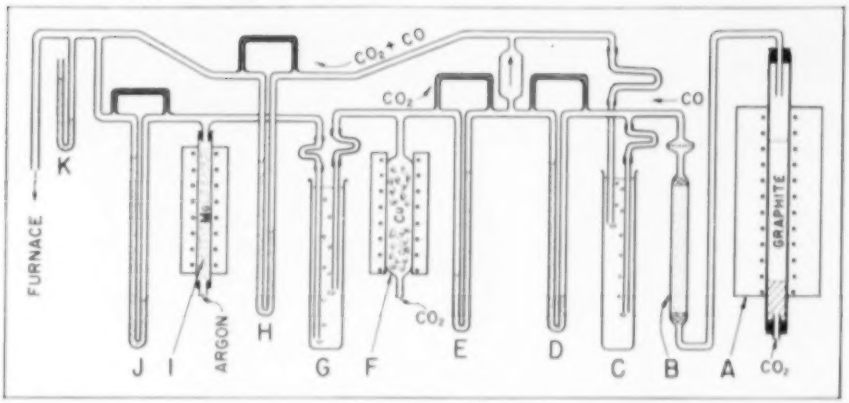

Fig. 5—Carbon monoxide-carbon dioxide mixer.

in series A were made in a pure dense alumina furnace tube, 1¼ in. ID, 1¾ in. OD, and 28 in. long. Some of the ingots in series A were quenched in granular tin by lowering the crucible quickly into a container full of granular tin in such a way that the top of the crucible was always kept inside the furnace. The results for the tin-quenched heats did not differ noticeably from the others.

Table I. Equilibrium Data on $H_2 + O = H_2O$

Heat No.	$\frac{P_{H_2O}}{P_{H_2}}$ (Corrected)	Pct Oxygen	K_1	Temperature, °C
		Series A		
A1	0.2505	0.0602	4.16	1550
A2	0.460	0.1080*	4.26	1550
A3	0.1134	0.0351	3.23	1600
A4	0.3870	0.1200*	3.10	1600
A5	0.0910	0.0350	2.60	1650
A6	0.2154	0.0854	2.52	1650
A7	0.1353	0.0627	2.16	1700
A8	0.0346	0.0082	4.22	1550
A9	0.1057	0.0250	4.22	1550
A10	0.2434	0.0584	4.17	1550
A11	0.4420	0.1100†	4.02	1550
A12	0.2425	0.0591	4.10	1550
A13	0.0456	0.0148	3.06	1600
A14	0.1188	0.0372	3.19	1600
A15	0.402	0.1275	3.17	1600
A16	0.0671	0.0249	2.69	1650
A17	0.1667	0.0656	2.54	1650
A18	0.1670	0.0779	2.14	1700
		Series B		
B1	0.3156	0.0775	4.07	1550
B2	0.1645	0.0402	4.09	1550
B3	0.1797	0.0551	3.26	1600
B4	0.2885	0.0897	3.21	1600
B5	0.1607	0.0755	2.13	1700
B6	0.0491	0.0227	2.16	1700

* Deviation from average ±0.0006, all others less than ±0.0003.
† Triplicate, all others duplicate.

The second column in Table I gives the ratio P_{H_2O}/P_{H_2}. The vapor pressure of water corresponding to each thermostatic temperature was obtained from the steam tables and corrected for a small deviation from ideality in order to obtain P_{H_2O}. The value of P_{H_2} was obtained by subtracting P_{H_2O} from the pressure over the saturator which is equal to the atmospheric pressure plus a small back pressure on the manometer M. The third column gives the average of duplicate analyses by the vacuum-fusion method.[6] The individual results for series A deviated from the average more than those for series B because the samples, obtained from the ingots of 6 to 7 g and weighing 1.8 to 2.4 g, were too small. Therefore, in series B the ingot weight was increased to 10 to 12 g to obtain samples weighing approximately 3.5 g. It was believed that experimental precautions and analytical results were better in series B than in series A.

The results are plotted in Fig. 3. The straight line passes through the points of series B. The average points plotted at each temperature in Fig. 4 show that there is very little uncertainty in the position of the line based on the experimental results. This line is represented by

$$\log K_1 = \frac{6670}{T} - 3.05 \qquad [4]$$

$$\Delta F^\circ_1 = -30{,}520 + 13.96\,T. \qquad [5]$$

The values of K_1 from Eq. 4 are 4.06, 3.24, 2.62, and 2.14 at 1550°, 1600°, 1650°, and 1700°C, respectively, with a maximum deviation of +4.9 pct and an average deviation of 2 pct at 1550°C.

The results show that the individual values of K_1 in the range of 0.0082 to 0.1275 at 1550°C agree very well with one another. If the temperature in series A were taken 4° lower at 1550°C, a small discrepancy with series B would be greatly minimized. At 1600°C, with the exception of heat A-13, in which a small error in oxygen analysis would cause a large deviation, the agreement between the two series is very good. It is therefore clear that scattering in the results is entirely within the experimental errors in temperature and in analysis.

Comparison With Other Data—Results of various investigators[2-5] are shown in Fig. 4, together with the author's line and the average points. Comparison with Fig. 3, drawn to the same scale, shows that the scattering in other investigations is considerably higher. Possible sources of error are not always evident but it is believed that they might be traced to 1) errors in oxygen analysis by the vacuum-fusion method, 2) thermal diffusion, and 3) uncertainties in temperature measurements. It is hoped that a brief discussion of these errors might explain the scattering in other investigations and disagreement with the present results.

1) It seems possible that previous investigations suffered to various degrees from errors in vacuum-fusion analysis of samples containing over 0.02 pct O. When such samples are dropped into a graphite crucible not equipped with baffles or a lid, they tend to spatter upon melting and yield low and erratic oxygen values. It was shown conclusively elsewhere[6] that the Bureau of Standards'[7,8] *acceptable range*, obtained arbitrarily by averaging results from reliable as well as faulty apparatus on the well known *cooperative steel samples*, are especially low in the range exceeding 0.010 pct O. It is therefore conceivable that a faulty apparatus capable of yielding results within the lower acceptable range may be in error by a substantial fraction. Thus, spattering,

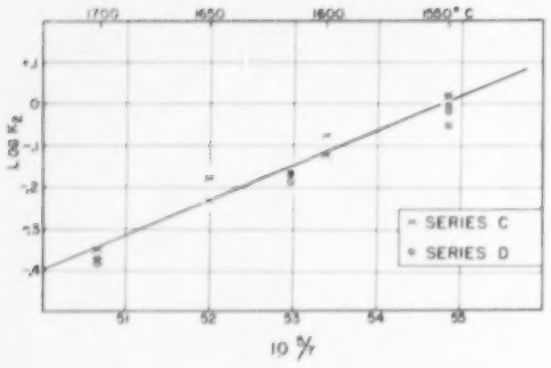

Fig. 6—Effect of temperature upon $K_2 = \frac{P_{CO_2}}{P_{CO} \times \%\underline{O}}$.

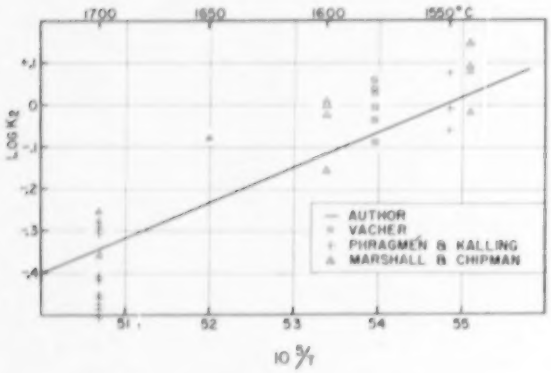

Fig. 7—Comparison with other data on K_2.

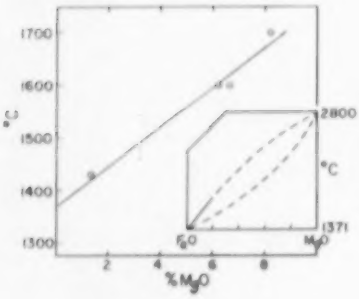

Fig. 8—Solubility of MgO in wüstite. Insert is the phase diagram MgO-FeO proposed by Bowen and Schairer.[17]

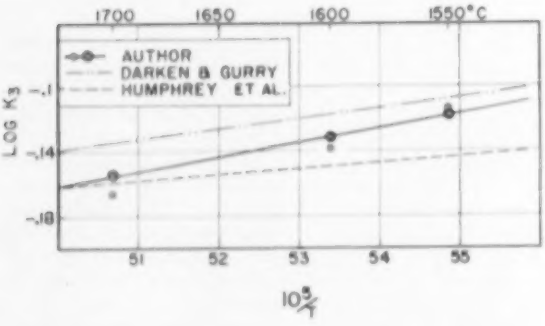

Fig. 9—Effect of temperature upon $K_3 = \frac{P_{H_2O}}{P_{H_2}} \cdot \frac{N_{Fe}}{N_{Fe_xO}}$.

which yields low and scattered oxygen values, would make the values of K_1 high and erratic.

2) When a mixture of H_2 and H_2O encounters a thermal gradient, the heavier molecules of H_2O concentrate in the colder zone. This phenomenon, known as thermal diffusion, is discussed adequately by Emmet and Schultz,[11] by Darken and Gurry,[1] and by Dastur and Chipman[5] in connection with the gas-metal equilibria. A sharp temperature gradient above the melt prevails especially when the metal is heated by induction and therefore the actual ratio of P_{H_2O}/P_{H_2} immediately above the metallic surface becomes lower than the inlet ratio used in the computation of K_1. Consequently, when this condition prevails the resulting value of K_1 becomes larger than its true value. Bubbling the gas mixture through the metal, as shown in Fig. 2, eliminates the error from thermal diffusion entirely. The bubbling technique used in this investigation is similar to that of Morris et al.,[12, 13] who successfully investigated equilibrium in the reaction of hydrogen with dissolved sulfur in liquid iron.

It is noteworthy that both analytical and thermal diffusion errors make the value of K_1 high and might therefore account for a substantial part of the difference between this and other investigations.

3) Errors in temperature measurements are important only when the optical measurements are not calibrated within a sufficiently large range and excessive extrapolation in the optical vs true temperature scale is made. Errors might also occur when the window through which the metal is sighted becomes dusty or foggy.

Vacher,[6] in his limited investigation, made four runs by using an induction furnace in which 100 g Fe was held at 1580°C. Mixtures of $H_2 + H_2O$ containing not more than 4.3 pct H_2O were passed over the liquid metal without preheating. The analysis of his samples containing up to 0.012 pct O was not subject to errors due to spattering. In spite of the errors from thermal diffusion, his average point is not too far from the author's line.

Several investigations, by means of essentially similar techniques, were carried out by Fontana,[4] Samarin,[7] and Dastur,[5, 9] with Chipman. These investigators used induction heating to melt their charge weighing 70 g or more and minimized the thermal diffusion by heating their gases with a platinum resistance coil in a refractory preheating tube. A part of their preheater, approximately 1½ in. from the gas outlet end, was not heated directly by the resistance coil. The tip of the preheater was kept a certain distance above the melt. Consequently, the gases reaching over the liquid metal encountered a temperature gradient; hence it is not certain that thermal diffusion was entirely eliminated in their experiments. It appears that some minor error might also have originated from their analytical procedure,[14, 15] since the graphite crucible used in their vacuum-fusion apparatus could not have prevented spattering entirely, as discussed elsewhere in detail.[8] No explanation was given by Dastur and Chipman[5] for the large difference above 1700°C between their results and those of Samarin and Chipman.[7]

Equilibrium in the Reaction $CO + \underline{O} = CO_2$

Several investigators[8, 16, 17] studied equilibrium in this reaction simultaneously with $C + \underline{O} = CO(g)$. The value of pct C × pct O was found to be 0.0025 at 1 atm of CO and approximately constant within a

fairly large temperature range. From this value it can be calculated that even in oxygen-saturated iron approximately 0.01 pct C must be present. When such melts freeze, carbon removes various amounts of oxygen and makes the values of K_s high and erratic. It was, therefore, the purpose of this section to investigate reaction 1 *without the interference of carbon*. To accomplish this, the partial pressure of CO was decreased 5 to 9.5 times by dilution with purified argon and therefore the *corresponding carbon content* at a given percentage of oxygen was also decreased by the same factor.

Experimental Method and Procedure—The experimental method and procedure used in this part were nearly identical with those in the first section. The gas mixer shown in Fig. 5 was similar to that used by Darken and Gurry.[1] Commercially pure CO_2 was dried and passed through the furnace *A*, filled with broken graphite rods, at 1200°C. All but a trace of CO_2 was converted into CO. The gas was passed through the ascarite tower *B*, 12 in. high and 1½ in. diam, in order to absorb a small amount of CO_2, and then accurately measured with the flowmeter *D*. It was mixed with CO_2 which had been dried and then passed through the furnace *F*, containing freshly reduced copper chips, at 500°C, in order to remove any oxygen, and delivered accurately by the flowmeter *E*. The bubbling towers *G* and *C* and a constant forepressure in the flowmeter *H* kept the flow rates, hence the ratio of P_{CO_2}/P_{CO} constant. The gas mixture was passed through the flowmeter *H* and mixed with purified argon from *I* and *J* and then led into the alumina inlet tube shown in Fig. 2. Repeated calibrations of flowmeters showed that deviation in the values of P_{CO_2}/P_{CO} was less than 1 pct.

A small trace of oxygen in argon, e.g., 0.02 pct, could have caused an error of 7.2 pct in CO_2 when $CO_2/CO = 0.05$ and $A/CO = 9.5$. In order to ascertain that argon contained much less oxygen than this amount, a run was made by bubbling a pure mixture of one part of hydrogen and 50 parts of argon through 15 g Fe at 1550°C for 2.5 hr. For this run the apparatus in Fig. 1 was modified so that hydrogen from the platinized asbestos train could be dried with phosphorus pentoxide and then passed through a flowmeter and mixed with argon from the magnesium train. Duplicate analysis of oxygen yielded 0.0017 pct O, which corresponds to $P_{H_2O}/P_{H_2} = 0.007$ as calculated from the value of K_1. Since all the H_2O was presumably formed from the reaction of hydrogen with a trace of oxygen, this value of P_{H_2O}/P_{H_2} corresponds to 0.007 pct O_2 in argon. Actually a part of 0.0017 pct O in iron was due to the dissolution of alumina at such low oxygen contents, and therefore the percentage of oxygen in argon must have been smaller than this indirectly estimated value.

Experimental Results—The results are presented in Table II. The second and third columns represent P_{CO_2}/P_{CO} as read from the flowmeters and the average of duplicate oxygen analysis, respectively. The heats in series C were made in an alumina furnace tube and quenched in granular tin. The flow rates of CO and argon were kept at 70 and 670 ml per min, respectively, by using a gas mixer which was similar to that shown in Fig. 5. Deviation in oxygen analysis was larger than in the succeeding series because the samples, weighing 1.8 to 2.4 g, were too small. The heats in series D yielded larger samples weighing approximately 3.5 g for more accurate oxygen analysis. These heats were made in the beryllia furnace tube shown in Fig. 2 by using CO and argon at the rates of 160 and 800 ml from the gas mixer shown in Fig. 5. In spite of all precautions, especially in series D, the scattering in the data were not minimized. It is difficult to account for the errors which are larger than the uncertainties in temperature and in P_{CO_2}/P_{CO} values. Any unknown source of error affecting the gas composition would make a large fractional error in P_{CO_2}/P_{CO} because this ratio, ranging from 0.055 to 0.113, is much smaller than P_{H_2O}/P_{H_2} corresponding to the same oxygen values in liquid iron. The cracking of CO, i.e., $2\ CO = CO_2 + C(s)$, in the cooler part of the inlet tube could have caused such errors, but in the absence of catalyzing metallic surfaces, the gas mixtures used in these experiments could not have cracked to deposit carbon according to Juliard, Rayet, and Ludé.[15] The gas inlet tube was replaced every morning to prevent the catalytic effect of any iron vapor that might have diffused into the tube at night, when the furnace was kept at 1200°C.

The results are shown in Fig. 6. The straight line representing a compromise between the two series is drawn according to the thermodynamic calculations in the next section, from which

$$\log K_s = \frac{8088}{T} - 4.438 \qquad [6]$$

$$F = -37{,}010 + 20.31\,T. \qquad [7]$$

Actually a line only 0.03 log unit lower and passing through the points for series D would have been preferable. The values of K_s from Eq. 6 are 1.00, 0.76, 0.586, and 0.46 at 1550°, 1600°, 1650°, and 1700°C, respectively.

Table II. Equilibrium Data on $CO + O = CO_2$

Heat No.	P_{CO_2}/P_{CO}	Pct Oxygen	K_s	Temperature, °C
		Series C		
C1*	0.0898	0.0860	1.044	1550
C2	0.0890	0.0866†	1.028	1550
C3	0.0854	0.1026	0.833	1600
C4	0.0751	0.1010	0.744	1600
C5	0.0711	0.1094	0.650	1650
C6	0.0633	0.1096†	0.577	1650
C7	0.0550	0.1320	0.417	1700
C8	0.0588	0.1328	0.443	1700
		Series D		
D1*	0.1128	0.1183	0.954	1550
D2	0.0874	0.0886	0.987	1550
D3	0.0671	0.0759	0.884	1550
D4	0.0496	0.0560	0.886	1550
D5	0.0492	0.0763	0.645	1615
D6	0.0631	0.0933	0.676	1615
D7	0.0657	0.0977	0.673	1615
D8	0.0529	0.1253	0.422	1700
D9	0.0418	0.1010	0.414	1700

* The ratio of argon to CO was approximately 9.5 in series C and 5.0 in series D.
† Deviation of duplicate analyses from average less than ±0.0008, all others less than ±0.0004.

Thermodynamic Calculations — Thermodynamic calculations and correlations in this paper require data on the standard free energy and enthalpy changes of gaseous reactions involving H_2, H_2O, CO, CO_2, and O_2. The thermodynamic functions for these gases, such as the free-energy function, $(F^\circ - H^\circ_0)/T$, and the relative heat content, $H^\circ - H^\circ_0$, are known with a very high degree of precision from the spectroscopic data. The results at various temperatures are tabulated in the literature. Carefully interpo-

lated values at 1873°K are given in Table III. Computation of the standard free-energy change ΔF° and the standard enthalpy change ΔH° from such tables are described in standard texts on thermodynamics,[22,23] and may be briefly outlined as follows: ΔF° for a reaction is calculated from the identity

$$\Delta F^\circ = T\,\Delta\,(F^\circ - H^\circ_o)/T + \Delta H^\circ_o \qquad [8]$$

in which ΔH°_o is obtained from the calorimetrically measured heat of reaction at 298°K, recently compiled by Rossini et al.[23] by the relation

$$\Delta H^\circ_o = \Delta H^\circ_{298} - \Delta(H^\circ - H^\circ_o). \qquad [9]$$

Further, ΔH° for a reaction is related to H°_o by

$$\Delta H^\circ = \Delta H^\circ_o + \Delta(H^\circ - H^\circ_o). \qquad [10]$$

Since ΔH° and ΔS° do not vary greatly, their values at 1873°K may be substituted in the linear standard free-energy change equation

$$\Delta F^\circ = \Delta H^\circ - T\,\Delta S^\circ \qquad [11]$$

in order to calculate ΔF° with a reasonably high degree of accuracy in the range of 200° above and below 1873°K.

Reactions 1 and 2 are related by the well known *water-gas reaction (wg)*

$$H_2 + CO_2 = H_2O + CO$$

$$K_{wg} = \frac{P_{H_2O} \times P_{CO}}{P_{H_2} \times P_{CO_2}} = \frac{K_1}{K_2} \qquad [12]$$

for which, from Table III

$$\Delta F^\circ = 6490 - 6.35\,T \qquad [13]$$

$$\log K_{wg} = -\frac{1418}{T} + 1.388. \qquad [14]$$

The straight line shown in Fig. 6 was drawn to represent the values calculated from K_{wg} and K_1 by

$$\log \frac{K_1}{K_{wg}} = \log K_2 = \frac{8088}{T} - 4.438. \qquad [6]$$

This is justified in view of the fact that this equation represents the data well and that the scattering of data does not permit a slightly lower line passing through the average points of series D as mentioned earlier.

The standard free energy of transfer of gaseous oxygen into liquid iron can be calculated as follows: For the reaction

$$H_2 + \tfrac{1}{2}O_2 = H_2O \qquad [15]$$

from Table III

$$\Delta F^\circ = -60{,}090 + 13.84\,T. \qquad [16]$$

Combination of Eq. 16 with Eq. 5 yields

$$\tfrac{1}{2}O_2 = \underline{O} \qquad [17]$$

$$\Delta F^\circ = -29{,}570 - 0.12\,T. \qquad [18]$$

Comparison With Other Data—The data of Vacher,[6] Phragmén and Kalling,[18] and Marshall and Chipman[17] are plotted in Fig. 7 together with the author's line for comparison. In all these investigations iron was melted by induction current. The mixtures of CO_2 and CO were not preheated, and therefore a small error from thermal diffusion must have prevailed in these experiments, although this is overshadowed by large scattering in their results.

Vacher[6] held 100 g Fe at 1580°C and passed gases containing 10.3 to 16.6 pct CO_2 over the metal. At the end of each run the induction current was shut off to cool the melt and the ingot was sampled and analyzed for oxygen. His results, for six runs containing less than 0.019 pct C, are on the average approximately 20 pct higher than the corresponding value of K_2 in this investigation.

Phragmén and Kalling[18] used a technique essentially similar to that of Vacher. They quenched their melts by dropping a ring of iron with a small amount of aluminum in order to retain the elements dissolved in the melt. Although they were essentially interested in determining the product pct $\underline{C} \times$ pct O, their runs containing less than 0.04 pct C are chosen and represented in Fig. 7.

Marshall and Chipman[17] circulated mixtures of CO_2 and CO around their furnace containing 75 to 100 g Fe at 1540°, 1600°, 1650°, or 1700°C. Their melts with less than 0.02 pct C were allowed to cool in the furnace, but those with higher carbon were cooled after adding aluminum and allowing the induction current to stir the melt for 30 sec. Assumption was made that aluminum preserved the carbon and oxygen which might otherwise have been lost by forming CO upon freezing. Their runs with less than 0.03 pct C are also shown in Fig. 7.

Comparison between Figs. 6 and 7 shows that scattering in this investigation is considerably smaller, though the results are not as accurate as those for reaction 1.

Equilibrium in the Reaction H_2 + Fe_xO (Liquid Wüstite) = H_2O + xFe(l) and Solubility of Oxygen in Liquid Iron

Equilibrium in the reduction of relatively pure liquid wüstite with hydrogen or CO above the melting point of iron has not been experimentally investigated. The reduction of liquid wüstite below the melting point of iron, however, has been investigated by Chipman and Marshall,[20] and by Darken and Gurry,[1] from which indirect results on equilibrium in reaction 3 can be calculated.

Experimental Procedure—The apparatus used in this part was the same as that in the first section. A magnesia crucible, 1¼ in. high and ¾ in. ID, 1/10 in. wall, was charged with 12 g Fe and placed in the furnace shown in Fig. 2. The gas inlet tube was centered to avoid contact with the crucible and the metal. The temperature of thermostat was varied at the rate of 0.03°C per min, and the surface of melt was observed with a well focused optical pyrometer. When the atmosphere over the metal became oxidizing, a thin film of oxide tended to cover the surface, at which time the thermostatic reading was taken. The procedure was repeated by gradually reaching a reducing atmosphere when the oxide on the surface disappeared. A distinct difference in the brightness of iron and wüstite made these observations possible. Heats S1, S3, and S4, presented in Table IV, were made by this method. It was discovered later that when the amount of iron oxide was large, the slag made a ring half way toward the center of iron but adhered to both the crucible and the metal. When the slag was exposed to a slightly reducing atmosphere, solid MgO-rich particles started moving on and across the metal and finally covered the entire surface. Heats S5, S6, and S10 were made to observe this type of reduction, as well as the previous process of oxidation and reduction. Repeated reduction of large amounts of

slag was distinctly observable, highly reproducible, and rather insensitive to a variation in the cooling rate of thermostat from 0.01° to 0.05°C per min.

At the end of some of the runs, iron was entirely oxidized under $P_{H_2O}/P_{H_2} = 1.8$ for 1 hr and then saturated with MgO under $P_{H_2O}/P_{H_2} = 1$ for 2 to 3 hr. Heat S12 was made by mixing equimolecular amounts of pure Fe_2O_3 and iron and holding the charge at 1430°C for 4 hr. The slag melts were then quenched and samples were obtained in the portion away from the walls of crucibles and analyzed for MgO in order to determine the composition of slag in equilibrium with liquid iron and magnesia.

Examination of the cross sections of crucibles showed that the penetration of slag into the walls was less than 1/32 in.

Attempts were made to obtain additional data by using various types of crucibles. Two heats made in pure dense beryllia crucibles and one in a porous heavy-wall magnesia crucible were not successful. Three runs made in pure dense alumina crucibles indicated that the slag preferentially adhered to the crucibles and dissolved nearly 40 pct alumina at 1550°C.

Results—The results on the heats made in pure dense magnesia crucibles are given in Table IV. The second column gives the average of oxidizing and reducing values of P_{H_2O}/P_{H_2} differing by approximately 1 pct. In addition, the average of duplicate values of P_{H_2O}/P_{H_2} differing less than 0.3 pct for heats S5, S6, and S10 for the reduction point of large amounts of liquid slag are included. The third column, containing the percentages of MgO in saturated liquid slags at 1430°, 1600°, and 1700°C, are represented in Fig. 8. The diagram for the system FeO-MgO, proposed by Bowen and Shairer,[27] presumably on the basis of the expected similarity to the NiO-MgO diagram, is inserted in the figure. A straight line passing through the melting point of wüstite represents the data well with an average accuracy of approximately ±0.3 pct MgO. The mol fraction of wüstite ($Fe_{1-x}O$) in liquid slag was calculated at 1550°, 1600°, and 1700°C from the straight line in Fig. 8 and tabulated in the fourth column. Darken and Gurry found that the composition of wüstite at 1524°C corresponds to $Fe_{0.95}O$. It is expected that increasing temperature would increase the amount of iron in wüstite but the error involved in the computation of mol fraction is trivial even when a larger variation of 0.96 to 1.00 is assumed in the atomic ratio of iron to oxygen.

The mol fraction of iron in the fifth column, i.e., $N_{Fe} = 1 - N_O$ where N_O = mol fraction of oxygen, is calculated from the percentage of oxygen obtained by substituting P_{H_2O}/P_{H_2} in the second column into K_1 of reaction 1.

The sixth column represents the equilibrium constant

$$K_2 = \frac{P_{H_2O}}{P_{H_2}} \cdot \frac{N^o_{Fe}}{N_{Fe_xO}} = \frac{P_{H_2O}}{P_{H_2}} \cdot \frac{N_{Fe}}{N_{Fe_xO}}. \quad [3]$$

Since x is very close to unity, N^o_{Fe} is very nearly equal to N_{Fe}. The activity of wüstite is assumed to be equal to its mol fraction because N_{Fe_xO} is close to unity and the FeO-MgO diagram suggests negligibly small deviation, if any, from ideality in the range of interest.

The results are plotted in Fig. 9. The solid line passes through the more reliable points, shown with double circles for the reduction of large amounts of slag. The single circles represent the oxidation reduction heats which agree very well with the preceding points. The largest deviation, which occurs at 1700°C, is less than 3 pct in the value of K_2. This line is represented by

$$\log K_2 = \frac{908}{T} - 0.615 \quad [19]$$

$$\Delta F^\circ = -4155 + 2.814\,T. \quad [20]$$

It is estimated that the average accuracy of K_2, based on heats S5, S6, and S10, is of the order of 1 pct.

Oxygen Pressure of Wüstite in Equilibrium with Liquid Iron—The oxygen pressure of pure wüstite in equilibrium with liquid iron is calculated from ΔF° obtained by combining Eqs. 18 and 20.

$$Fe_xO(l) = xFe(l) + \tfrac{1}{2}O_2$$
$$\Delta F^\circ = 55{,}935 - 11.026\,T. \quad [21]$$

The logarithm of oxygen pressure from this equation agrees well with that from Darken and Gurry.[1] For example, at 1600°C, $\log P_{O_2} = -8.23$ from Eq. 21, and $\log P_{O_2} = -8.20$ from their results.

Comparison with Other Results—Darken and Gurry,[1] in their outstanding paper *The System Iron-Oxygen*, have calculated the values of the equilibrium constant for the reaction

$$CO + Fe_xO \text{ (liquid wüstite)} = CO_2 + xFe(l) \quad [22]$$

by means of the free energy of formation of magnetite.* The author converted their results into K_2 for reaction 3 by using the values of $K_{w.g}$† in their paper because they had converted P_{H_2O}/P_{H_2} in equilibrium with magnetite into P_{CO_2}/P_{CO} by using $K_{w.g}$. The resulting equation is

$$\log K_2 = \log \frac{P_{H_2O}}{P_{H_2}} = \frac{666}{T} - 0.472 \quad [23]$$

the accuracy of which is within approximately 2 pct in K_2 as claimed by these investigators. Actually, if the values of $K_{w.g}$ in this paper were used for converting their data, $\log K_2$ of Eq. 22 would have been larger by only 0.02. The agreement of their calculated results with this investigation is unexpectedly good, as shown in Fig. 9.

* The author did not attempt to obtain equilibrium data on this reaction because of the experimental difficulties in varying P_{CO_2}/P_{CO} very gradually without modifying the apparatus. Further, it may be noted that the error in the determination of equilibrium in this reaction is higher than that in reaction 3 since P_{CO_2}/P_{CO} is approximately four times farther from unity than the corresponding P_{H_2O}/P_{H_2}.

† Darken and Gurry's objection to a small difference between their preferred $K_{w.g}$ and that from the new spectroscopic data cannot be settled without further precise experimental investigations. The author preferred the new values of $K_{w.g}$ because the results on reactions 1 and 2 correlated better.

Table III. Free-Energy Functions and Relative Heat Contents of H_2, H_2O, CO, CO_2, and O_2*

	T, °K	H_2	H_2O	CO	CO_2	O_2
$(F^\circ - H^\circ_0)/T$	1873	−37.193	−52.735	−53.563	−61.063	−55.576
$H^\circ - H^\circ_0$	1873	13,652	18,212	14,534	22,264	15,082
$H^\circ - H^\circ_0$	298.16	2024	2365	2073	2238	2075
References		19, 20	20	20	21	22

* Heats of reaction at 298°K, necessary for thermodynamic calculations in this paper, are $\Delta H^\circ_{298} = -67{,}636$ cal for $CO + \tfrac{1}{2}O_2 = CO_2$ and $\Delta H^\circ_{298} = -57{,}798$ cal for $H_2 + \tfrac{1}{2}O_2 = H_2O(g)$ as taken from Rossini et al.[26]

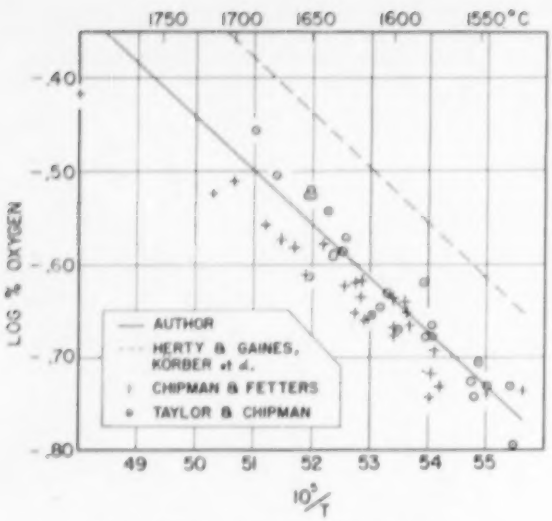

Fig. 10—Solubility of oxygen in liquid iron.

Humphrey, King, and Kelley[29] have recently calculated the free-energy change for the reaction

$$H_2 + Fe_{0.947}O = H_2O + 0.947\,Fe \qquad K_3 = \frac{P_{H_2O}}{P_{H_2}}$$

and tabulated the values of ΔF°, ΔH°, and K_3 at 298°K, and at 100° intervals and at transition and melting points of iron and wüstite from 400° to 2000°K. For this purpose, they obtained new data on the heat of formation of wüstite by using combustion and solution calorimetry and correlated their results with the available data. The best choice for the heat of formation of wüstite at 298°K was found to be −63,800±200 cal per mol. The remaining necessary thermodynamic data were obtained from the literature to perform the calculations. Their values of log K_3, represented in Fig. 9, agree well with this investigation, though a readily possible error of 500 cal in ΔH°_{298} could have shifted their line considerably on the sensitive vertical scale.

Chipman and Marshall[30] obtained equilibrium data on the reduction of liquid wüstite with hydrogen below the melting point of iron. Darken and Gurry also obtained similar data by using CO and they showed that, although their results collated well with those of Chipman and Marshall, both sets of data were questionable because of the contamination of wüstite with unknown amounts of silica. The values of log K_3 calculated from both of these investigations are roughly 0.5 lower than those of the author and lie outside of Fig. 9.

Solubility of Oxygen in Liquid Iron—Solubility of oxygen in liquid iron is obtained by means of the data on reactions 1 and 3. Subtraction of Eq. 4 from Eq. 19, and the corresponding reactions lead to

$$Fe_xO(l) = xFe(l) + \underline{O} \qquad K_4 = \frac{\%\underline{O} \times N_{Fe}}{N_{Fe_xO}} \qquad [24]$$

$$\log K_4 = -\frac{5762}{T} + 2.435. \qquad [25]$$

For the maximum concentration of oxygen in liquid iron the wüstite must be pure, i.e., its mol fraction must be unity. The mol fraction of iron is close to unity, and its average value from 1550° to 1750°C is 0.990. Hence, the solubility of oxygen in liquid iron, i.e., pct $\underline{O}$ (maximum), is

$$\log \%\,\underline{O}\ (\text{maximum}) = \frac{5762}{T} + 2.439. \qquad [26]$$

This equation is represented by the solid line in Fig. 10. The accuracy in pct $\underline{O}$ (maximum) is estimated as follows: Error in K_3 is of the order of 1 pct. The effect of errors in temperature on K_3 is very small. The maximum deviation in K_4 is +4.9 pct and average deviation less than ±2 pct. The probable accuracy is therefore approximately ±3 to 5 pct of dissolved oxygen.

The solubility values, calculated from the foregoing equation, are 0.190, 0.231, 0.278, 0.331, and 0.391 at 1550°, 1600°, 1650°, 1700°, and 1750°C, respectively.

Comparison with Direct Determinations—Direct determination of the solubility of oxygen in liquid iron consists of analyzing the samples taken from the metallic bath in contact with oxide slags at various temperatures. The samples, obtained by casting directly into a mold from the furnace or from a spoon usually coated with a refractory skin, contain streaks and globules of slag which are trapped in the frozen metal. When the melt is allowed to freeze in the crucible, the cooling rate is not sufficient to prevent the loss of oxygen by precipitation. Sampling by dipping a mold into the melt, or by suction into a tube, does not eliminate the trapped slag entirely. In addition, various errors originate from impurities in iron oxide, temperature measurements, and analytical procedures. It is therefore not surprising that scattering in the available data is rather large.

Table IV. Equilibrium Data on $H_2 + Fe_xO(l) = H_2O + xFe(l)$

Heat No.	P_{H_2O}/P_{H_2}*	Pct MgO in Slag	Mol Fraction N_{Fe_xO}†	Mol Fraction N_{Fe}‡	K_3	Temperature, °C
S1§	0.6580	6.22	0.897	0.993	0.728	1600
S3	0.5910	8.22	0.857	0.990	0.683	1700
S4	0.7121	—	0.919	0.994	0.770	1550
S5	0.7061	—	0.919	0.994	0.764	1550
S6	0.6689	6.65	0.897	0.993	0.740	1600
S10	0.6087	—	0.857	0.990	0.703	1700
S12	—	1.35	—	—	—	1430

* Corrected for a small deviation from ideality.
† Calculated from Fig. 8.
‡ Calculated from $1-N_O$, and N_O from pct $\underline{O}$ obtained by substituting values in second column into K_3.
§ All listed heats were made in pure dense MgO crucibles.

The first result on the solubility of oxygen *at a known temperature* was reported by the Bureau of Standards,[31] which gave a value of 0.21 pct at the melting point of electrolytic iron under air. This value was later reproduced by Tritton and Hanson,[32] who melted their charge in magnesia crucibles under nitrogen.

Herty and Gaines[33] melted 50 lb Fe in magnesia crucibles under air in an induction furnace, and sampled their melts with a fireclay-coated spoon. Their results, ranging from 1535° to 1734°C, agree with those of Körber and co-workers,[34, 35] who used an essentially similar technique. The broken line in Fig. 10 represents the results of both investigations,

whose individual points scatter considerably and fall outside of the plot in the range above 1680°C.

Chipman and Fetters[34] melted 70 lb Fe by induction in magnesia crucibles under pure nitrogen and air. The surface of their melts was covered with iron oxide slags containing small amounts of MgO, CaO, and SiO_2. The slag and the metal samples were taken by dipping small split molds ½ to 2 in. ID. The metal samples, analyzed by the vacuum-fusion method, indicated no consistent difference for the slags containing 90 to 96 pct total iron oxide, hence no correction was made for the variation in slag composition. In view of the fact that their data differed considerably from the previously accepted results of Herty and Gaines, and Körber and coworkers, another investigation was carried out by Taylor and Chipman[35] to resolve the difference and to obtain additional data. For this purpose they used a rotating induction furnace and a copper sampler into which the liquid metal was sucked. Their data, obtained under widely varying conditions and procedures, confirmed those of Chipman and Fetters and disproved the results of the preceding investigators. Although both sets of data scatter considerably, because of the unavoidable experimental errors, the agreement with this investigation is good, as shown in Fig. 10. It is doubtful that the errors in the direct determination of solubility can be reduced sufficiently to attain the accuracy of the indirectly calculated results presented in this paper.

Summary

Equilibria in the reactions of hydrogen, and CO with dissolved oxygen in liquid iron, and equilibrium in the reduction of ferrous oxide with hydrogen have been investigated in the range of 1550° to 1700°C. The experimental results are represented by

$$\log K_1 = \log \frac{P_{H_2O}}{P_{H_2} \times \%\,\underline{O}} = \frac{6670}{T} - 3.05$$

$$\log K_2 = \log \frac{P_{CO_2}}{P_{CO} \times \%\,\underline{O}} = \frac{8088}{T} - 4.438$$

$$\log K_3 = \log \frac{P_{H_2O} \times N_{Fe}}{P_{H_2} \times N_{Fe_xO}} = \frac{908}{T} - 0.615.$$

Solubility of oxygen in liquid iron, calculated from K_1 and K_2, is expressed by

$$\log \%\,\underline{O}\ (\text{maximum}) = -\frac{5762}{T} + 2.439\,.$$

The result is subject to much smaller errors than the direct determinations.

The related thermodynamic equations are derived and correlated by using recent spectroscopic and thermal data on H_2, H_2O, O_2, CO, and CO_2.

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References

[1] L. S. Darken and R. W. Gurry: The System Iron-Oxygen, Part I. *Journal* Amer. Chemical Soc., 1945, vol. 67, p. 1398; Part II, 1946, vol. 68, p. 798.

[2] *Basic Open Hearth Steelmaking*. Second Ed., 1951. New York. AIME.

[3] N. A. Gokcen: Improved Vacuum-Fusion Method for Determination of Oxygen and Nitrogen in Metals. Submitted for publication.

[4] N. A. Gokcen: Attainment of Equilibrium in Gas-Metal Reactions. *AIME Trans.*, 1953, vol. 197, p. 191; JOURNAL OF METALS, February 1953.

[5] H. C. Vacher: The System Liquid Iron-Carbon Oxides. *Journal of Research* U. S. Bureau of Standards, 1933, vol. 11, p. 541.

[6] M. G. Fontana and J. Chipman: Equilibrium in the Reaction of Hydrogen with Ferrous Oxide in Liquid Iron at 1600°C. *Trans.* ASM, 1936, vol. 24, p. 313.

[7] J. Chipman and A. M. Samarin: Effect of Temperature Upon Interaction of Gases with Liquid Steel. *AIME Trans.*, 1937, vol. 125, p. 331.

[8] M. N. Dastur and J. Chipman: Elimination of the Thermal-Diffusion Error in Studies of Gas-Metal Equilibrium. Physical Chemistry of Process Metallurgy. *Discussions* Faraday Soc., 1948, No. 4, p. 100.

[9] M. N. Dastur and J. Chipman: Equilibrium in the Reduction of Hydrogen with Oxygen in Liquid Iron. *AIME Trans.*, 1949, vol. 185, p. 441; JOURNAL OF METALS, August 1949.

[10] J. G. Thompson, H. C. Vacher, and H. A. Bright: Cooperative Study of Methods for the Determination of Oxygen in Steel. *AIME Trans.*, 1937, vol. 125, p. 246.

[11] P. H. Emmett and J. F. Schultz: Gaseous Thermal Diffusion. *Journal* Amer. Chemical Soc., 1933, vol. 55, p. 1376.

[12] J. P. Morris and A. J. Williams, Jr.: The Effect of Silicon on the Activity of Sulphur in Liquid Iron. *Trans.* ASM, 1949, vol. 41, p. 1425.

[13] J. P. Morris and R. C. Buehl: The Effect of Carbon on the Activity of Sulphur in Liquid Iron. *AIME Trans.*, 1950, vol. 188, p. 317; JOURNAL OF METALS, February 1950.

[14] J. Chipman and M. G. Fontana: Determination of Oxygen and Nitrogen in Steel. *Industrial and Engineering Chemistry* Analytical Ed., 1935, vol. 7, p. 391.

[15] S. Marshall and J. Chipman: Improvements in the Accuracy of the Vacuum-Fusion Method for the Determination of Oxygen in Steel. *AIME Trans.*, 1940, vol. 140, p. 127.

[16] G. Phragmén and B. Kalling: The Effect of Temperature on the Equilibrium between Carbon and Oxygen in Liquid Iron and in a Gas Phase. *Jernkontorets Annaler*, 1939, vol. 123, p. 199.

[17] S. Marshall and J. Chipman: The Carbon-Oxygen Equilibrium in Liquid Iron. *Trans.* ASM, 1942, vol. 30, p. 695.

[18] A. Jullard, R. Rayet, and A. Ludé: A Kinetic Study of the Dissociation of Carbon Monoxide Accompanying the Reduction of Metallic Oxides. Physical Chemistry of Process Metallurgy. *Discussions* Faraday Soc., 1948, No. 4, p. 193.

[19] R. H. Sherman and W. F. Giauque: Free Energies and Entropies of Hydrogen, Chlorine and Hydrogen Chloride from Spectroscopic Data. *Journal* Amer. Chemical Soc., 1953, vol. 75, p. 2007.

[20] D. D. Wagman, J. E. Kilpatrik, W. J. Taylor, K. S. Pitzer, and F. D. Rossini: Heats, Free Energies, and Equilibrium Constants of Some Reactions Involving O_2, H_2, H_2O, C, CO, CO_2, and CH_4. *Journal of Research* U. S. Bureau of Standards, 1945, vol. 34, p. 143.

[21] H. W. Woolley: Thermodynamic Functions for Carbon Dioxide in the Ideal Gas State. *Journal of Research* U. S. Bureau of Standards, 1954, vol. 52, p. 289.

[22] H. W. Woolley: Thermodynamic Functions for Molecular Oxygen in the Ideal Gas State. *Journal of Research* U. S. Bureau of Standards, 1948, vol. 40, p. 163.

[23] L. S. Darken and R. W. Gurry: *Physical Chemistry of Metals*. 1953, p. 231. New York. McGraw-Hill Book Co.

[24] S. Glasstone: *Thermodynamics for Chemists*. 1947, Second Ed., p. 206. New York. D. van Nostrand Co.

[25] F. D. Rossini, D. D. Wagman, W. H. Evans, S. Levine, and I. Jaffee: Selected Values of Chemical Thermodynamic Properties. *Circular 500* U. S. Bureau of Standards, 1952.

[26] J. Chipman and S. Marshall: The Equilibrium FeO + H_2 = Fe + H_2O at Temperatures up to the Melting Point of Iron. *Journal* Amer. Chemical Soc., 1940, vol. 62, p. 299.

[27] N. L. Bowen and J. F. Schairer: The System MgO—FeO—SiO_2. *Amer. Journal of Science*, 1935, vol. 29, p. 151.

[28] G. L. Humphrey, E. G. King, and K. K. Kelley: Some Thermodynamic Values for Ferrous Oxide. *Report of Investigations 4870* Bureau of Mines, 1952.

[29] Oxygen in Iron Melted under Air or Gas Flame. *Chemical and Metallurgical Engineering*, 1922, vol. 26, p. 778.

[30] F. S. Tritton and D. Hanson: Ferrous Alloys Research—Part II: Iron and Oxygen. Journal Iron and Steel Inst., 1924, vol. 110, p. 90.

[31] C. H. Herty, Jr. and J. M. Gaines: Effect of Temperature on the Solubility of Iron Oxide in Iron. *AIME Trans.*, Iron and Steel Technology in 1928, p. 142. See also *Mining and Metallurgical Investigations*, Bull. 34, Carnegie Institute of Technology, 1927; C. H. Herty, Jr.: *AIME Trans.*, 1926, vol. 73, p. 1107.

[32] F. Körber: Investigations on the Behavior of Manganese in Steelmaking. *Stahl und Eisen*, 1932, vol. 52, p. 123.

[33] F. Körber and W. Oelsen: Relations Between Slags Consisting Almost Entirely of MnO and FeO, and Iron Containing Manganese. *Mitteleirges Kaiser Wilhelm Inst. Für Eisenforsch*, 1932, vol. 14, p. 181.

[34] J. Chipman and K. L. Fetters: The Solubility of Iron Oxide in Liquid Iron. *Trans.* ASM, 1941, vol. 29, p. 953.

[35] C. R. Taylor and J. Chipman: Equilibria of Liquid Iron and Simple Basic and Acid Slags in a Rotating Induction Furnace. *AIME Trans.*, 1943, vol. 154, p. 228.

Discussion of this paper sent (2 copies) to AIME by Jan. 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957, and in JOURNAL OF METALS, October 1957.

Hydrogen in Steelmaking Slags

A modification of the vacuum fusion method has been used to analyze slags for hydrogen. Analyses of synthetic slags brought into equilibrium with atmospheres containing hydrogen or water vapor show that only water vapor dissolves in slags. Slag and metal samples from a number of industrial heats have been analyzed and the important role of the slag in determining the hydrogen content of the metal has been confirmed. A tentative explanation of the differences noted in acid and basic open hearth and basic electric furnace practice is given.

by J. H. Walsh, J. Chipman, T. B. King, and N. J. Grant

WITH the development of adequate sampling and analysis techniques, much information has been obtained concerning the behavior of hydrogen in the steel bath during the course of steelmaking operations.[1-7] From studies of this type it has become clear that the slag has an important role to play in determining the hydrogen content found in commercial products. A knowledge of the behavior of hydrogen in slags is necessary to round out our knowledge of hydrogen in steelmaking practice; with this information we are better able to assess practical methods of control.

In this paper a method developed for analyzing slags for hydrogen content, studies of the solubility of hydrogen in synthetic slags, and studies of the variation of hydrogen content in slag and steel in industrial heats will be described.

Previous Work—While very little has been done in the past to determine the hydrogen content of metallurgical slags, measurements have been made on such slag-like materials as geologic magmas and glasses. Goranson[8] has made extensive studies of the solubility of water in natural and synthetic granites. Many workers have investigated the solubility of gases in synthetic and commercial glasses,[9,10] but the recent work of Russell[11] is the most extensive. Russell found that the solubility of water in glass was proportional to the square root of the water vapor pressure in water vapor-oxygen mixtures. It was found that the solubility could either increase or decrease with temperature depending on the glass composition.

Wentrup, Fucke, and Rief,[1] and Piper, Hagedorn, and Backes[2] have extracted hydrogen by holding a slag at 1300° and 800°C respectively in vacuum. Wentrup et al. reported hydrogen and water vapor as evolved together while Piper et al. passed the evolved gases from the hot extraction treatment over hot ferromanganese to reduce the evolved water vapor to hydrogen and, therefore, reported the analyses in terms of total dissolved hydrogen. Yavoiskii[12] has reported hydrogen and nitrogen analyses on steelmaking slags. Dobrokhotov, Povolskii, and Khan[13] have studied the hydrogen content of basic open hearth steel under slags of varying viscosity. These authors reported that the hydrogen content of the steel bath increased as the fluidity of the slag was increased by the addition of bauxite. They recommended that a viscous slag be used and the steel tapped without deoxidation in the furnace to ensure a low final hydrogen content.

J. H. WALSH, formerly Graduate Student, Massachusetts Institute of Technology, is now with Mines Branch, Dept. of Mines and Technical Surveys, Ottawa, Canada. J. CHIPMAN, T. B. KING, and N. J. GRANT, Members AIME, are Professor, Assistant Professor, and Associate Professor, respectively, Dept. of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

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Analysis of Slags for Hydrogen

Development of Apparatus—The vacuum fusion analysis equipment described by Shields, Chipman, and Grant[6] was modified for the analysis of slags.[6] This method depends upon the reduction of water in the slag to hydrogen, which is readily determined by the method used for hydrogen in steel.

Preliminary experiments were made with a eutectic ferrosilicon melt as the reducing agent. Other experiments included the use of graphite and molybdenum crucibles. The ferrosilicon alloy bath was found to produce a thick coating on the furnace tube which could adsorb hydrogen. Graphite produced CO by the reduction of FeO, MnO, and SiO_2 in such quantities that analysis for hydrogen was virtually impossible. Molybdenum, while giving a low blank value, could reduce the slag sufficiently to produce a volatile oxide which again was found to adsorb hydrogen.

The arrangement finally adopted is shown in Fig. 1. The molybdenum sheet served as the induction-heated susceptor, and was separated from the escaping gases by alumina guide tubes. An outer jacket of alumina protected the quartz furnace tube, and alumina and quartz stools completed the assembly.

The falling sample is shown wrapped in aluminum foil, 0.002 in. thickness, which acted as the reducing agent. This foil was carefully washed in acetone and carbon tetrachloride and then dried in hot air before wrapping the weighed slag sample for charging into the apparatus. Investigation of the hydrogen content of the aluminum foil itself showed that a small quantity of hydrogen was released in vacuum, but had no relation to the weight of the aluminum charged. This quantity of hydrogen was

found to decrease to a negligible value with successive additions of aluminum. This was taken to mean that no large quantity of hydrogen was present in the cleaned aluminum foil itself, but that the aluminum vapor which formed in vacuum and coated the ceramic assembly caused a release of hydrogen from these surfaces, probably from water vapor adsorbed on the refractory. In daily analysis two 0.1 g pieces of aluminum foil were charged before the beginning of the analysis to flush out this hydrogen.

In addition, a blank correction was necessary because of the hydrogen released from the refractories. This is an appreciable quantity and leads to higher blank corrections than are encountered in steel analysis. Fortunately the hydrogen content of the slags is also much higher than that of steels.

In the development of the analytical technique two separate questions arose: whether all the hydrogen contained in the slag sample had been released, and whether all the released hydrogen reached the gas analysis section. To answer both questions a calibration procedure was adopted. Borax, sodium tetraborate decahydrate $Na_2B_4O_7 \cdot 10H_2O$, was chosen as a standard. This salt is stable between relative humidities of 0.39 and 0.99 at 25°C,[14] and contains a high proportion of hydrogen (5.27 pct), so that adsorbed water on the surface does not have an appreciable effect on the results. Moreover, the lower hydrates are easily distinguished, being considerably whiter in appearance, so that it is possible to avoid selecting crystals containing less hydrogen than expected. A disadvantage in the use of sodium tetraborate decahydrate is the small weight that is necessary to provide the proper amount of gas for analysis. A typical series of results of calibration tests using this hydrate is given in Table I.

Some difficulty was found in the development of a satisfactory molybdenum susceptor. After a day's analysis the susceptor could not be recovered since it was usually bound to the refractory by some of the liquid slag and the use of welded susceptors was costly. A method of crimping thin sheets into a cylinder was developed so that when the inductive field was applied, sparking along the lines of the crimp would cause it to weld together. The molybdenum embrittled rapidly after even a short time at operating temperatures so that it was necessary to avoid rapid changes of temperature to prevent the weld from cracking from thermal shock. The measured temperature was usually 1450°C, with the probable true temperature in the reaction crucible somewhat above 1500°C.

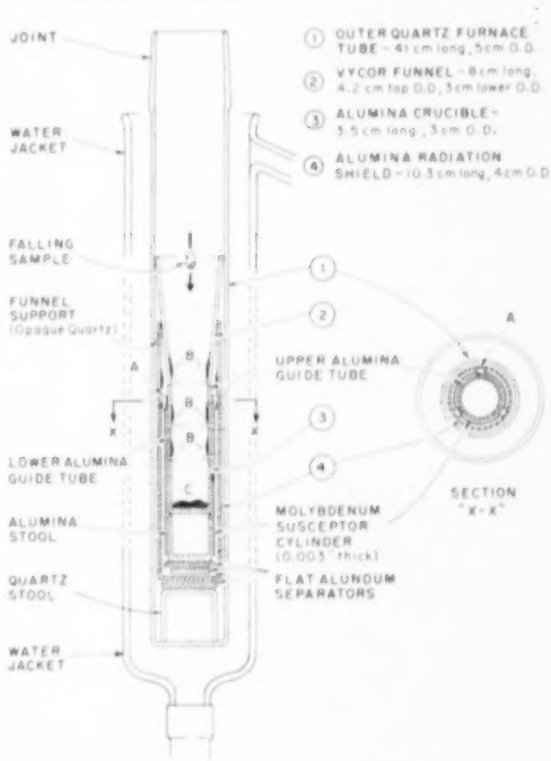
JOINT
WATER JACKET
FALLING SAMPLE
FUNNEL SUPPORT (Opaque Quartz)
LOWER ALUMINA GUIDE TUBE
ALUMINA STOOL
QUARTZ STOOL
WATER JACKET
1 OUTER QUARTZ FURNACE TUBE - 41 cm long, 5 cm O.D.
2 VYCOR FUNNEL - 8 cm long, 4.2 cm top O.D., 3 cm lower O.D.
3 ALUMINA CRUCIBLE - 3.5 cm long, 3 cm O.D.
4 ALUMINA RADIATION SHIELD - 10.5 cm long, 4 cm O.D.
UPPER ALUMINA GUIDE TUBE
MOLYBDENUM SUSCEPTOR CYLINDER (0.003" thick)
FLAT ALUNDUM SEPARATORS
SECTION "X-X"

Fig. 1—Furnace assembly for slag analysis. *A* represents three wedges of Alundum; *B*, areas where deposits form; and *C*, slag sample.

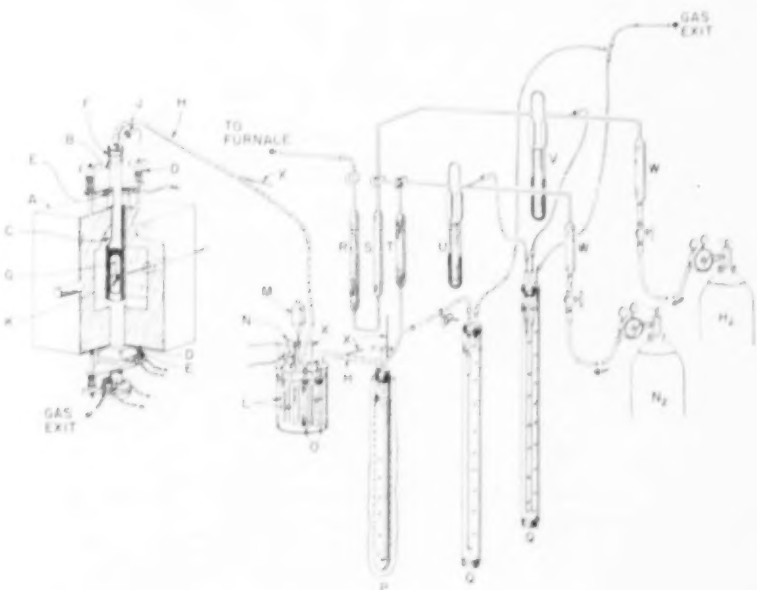

Fig. 2—Apparatus for equilibrating slags with gas mixtures containing hydrogen or water vapor.

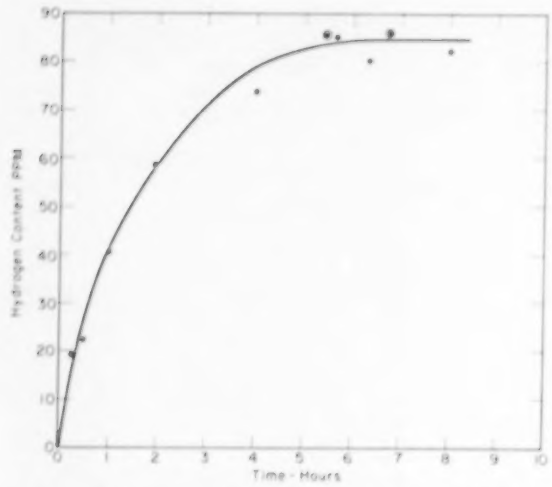

Fig. 3—Kinetic study of 40 pct CaO-40 pct SiO_2-20 pct Al_2O_3 slag at 1550°C; p_{H_2O} equals 1 atm. Circled points indicate approach from high hydrogen content.

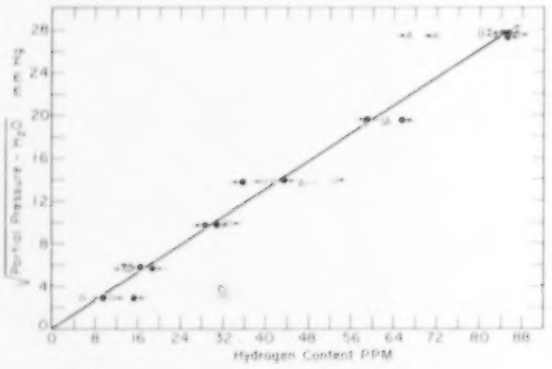

Fig. 4—Hydrogen solubility as a function of $p_{H_2O}^{1/2}$ in a 40 pct CaO-40 pct SiO_2-20 pct Al_2O_3 slag. Closed circles represent 1450°; open circles, 1550°; and open triangles, 1370°C.

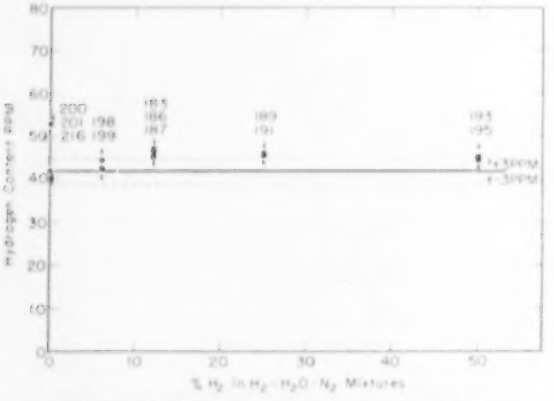

Fig. 5—Effect of hydrogen gas on solubility of hydrogen in a 40 pct CaO-40 pct SiO_2-20 pct Al_2O_3 slag. Water vapor in atmosphere is constant at 25 pct. Line through 42 ppm is obtained from Fig. 4.

Standard Operation—For the most part, the vacuum fusion apparatus was operated in a two-day cycle. On the first day, the furnace assembly was taken apart from the previous day's analysis and a new susceptor and alumina crucible installed. For the remainder of the day, the system was baked out at a temperature of about 1550°C. On the second day, after a brief bake-out, additions of aluminum foil were made to flush hydrogen from the refractories, followed by calibration with borax. From 10 to 15 separate slag samples were then analyzed, each weighing from 0.1 to 1.5 g, depending upon the anticipated hydrogen content. Each sample was wrapped in about 0.1 g cleaned aluminum foil. At the close of an analytical run, a second calibration with borax was made.

On each analysis a check was made for water vapor in the collected gas by expanding the gas through a cold trap. Within the limits of accuracy of this method no evidence of water vapor was found in the gases analyzed from the slags.

The slags that gave the least difficulty in analysis were those in the lime-silica-alumina system; those that gave the most difficulty (due to crucible attack) were high in iron oxide. The variation between separate analyses was less for synthetic slags than for industrial slags. For synthetic slags, average variations were usually in the range of ±2 ppm H, while for industrial slags variations of ±3 ppm were found, see Table II.

Experimental Technique for Equilibrating Synthetic Slags with Mixtures of Hydrogen, Water Vapor, And Nitrogen

Apparatus—A gas train was built which could produce controlled mixtures of water vapor, hydrogen, and nitrogen. The general arrangement of the equipment is shown in Fig. 2. The water vapor content of the gas stream was controlled by passing the gas through water saturation towers located in a controlled temperature bath. For atmospheres containing water vapor, no purification, except for oil removal, was used on the gases of commercial grade. For mixtures of hydrogen and nitrogen gases, the gases were mixed together, passed over a palladium-type catalyst, and then through a tower containing *Drierite* and *Ascarite* to remove water vapor and CO_2. The mixed and metered gases were conducted to the furnace through copper tubing, which was heated when necessary by a resistance winding to prevent condensation of water.

The furnace used in this investigation was of the vertical Globar tube type, as described by Larson and Chipman.[15] The gases were led through a Transite furnace head down the Zirco furnace tube, which provided a gas-tight reaction chamber. A mercury seal or a Transite cover was used at the bottom of the Zirco tube to complete the assembly. This furnace was capable of operation at temperatures as high as 1600°C for extended periods with a temperature control of about ±2°C. The slags were held in a 10 cu cm Pt crucible suspended by Pt-13 pct Rh wires 0.020 in. in diam.

Experimental Procedure—The slags were prepared by mixing the chemically pure constituents. To assure approach to equilibrium from both sides, the slags were first held at temperature for at least an hour, in air or in steam respectively for runs with increasing or decreasing hydrogen content. The appropriate atmosphere was then admitted and after equilibration the slags were quenched by low-

ering the crucible rapidly into either mercury or water. No variation in hydrogen content was found for a water quench as compared with a mercury quench.

Some experimentation was necessary to determine a melt size that would give a slag size suitable for charging into the vacuum fusion apparatus. Since from 0.5 to 1.5 g was required it was decided to charge the slag preferably in one piece or at least in not more than three pieces. To remove the slag from the crucible it was often necessary to heat the crucible in a Bunsen flame to red heat and then dip it rapidly into water to crack the slag away from the platinum.

The slag samples so obtained were promptly bottled and the bottles stored in a desiccator. Samples analyzed over a period of three weeks or more showed no change in hydrogen content within the uncertainty of analysis. On one occasion, a sample from one run was immersed in water, air-dried, and then analyzed with no apparent change when compared with slags handled in the normal way. The slags were handled with tongs and precautions were taken to prevent the contamination of the surface with grease or dirt.

Experimental Results of Synthetic Slag Studies

The lime-silica-alumina system was chosen for the first studies because slags of these compositions could be held without difficulty in platinum crucibles, and because at one composition a 200° temperature variation was possible. The results of solubility studies in this system were not complicated by the possibility of oxidation. The slags on cooling were clear and glass-like.

Table I. Calibration with Sodium Tetraborate Decahydrate*

Weight of Sample, Mg	Uncorrected Value, Ppm	Blank Correction, Ppm	Corrected Value, Ppm	Deviation, Pct
3.10	54,700	600	54,100	+2.7
2.63	55,350	2,050	53,500	+1.1
2.22	58,100	500	54,600	+3.6
2.68	52,100	300	51,800	−1.7
2.30	51,800	400	51,400	−2.5
3.23	52,100	800	51,300	−2.7
2.38	58,300	1,900	53,400	+1.3

* Taken over a period of one month. Theoretical hydrogen content of $Na_2B_4O_7 \cdot 10H_2O$ = 52,700 ppm.

A brief kinetic study was made by reacting a slag of 40 pct CaO-40 pct SiO_2-20 pct Al_2O_3 composition with an atmosphere of steam for different times at 1550°C after first melting in air for at least 1 hr. The results of this work are shown in Fig. 3. Two heats approaching equilibrium from the high hydrogen side were included to fix the saturated hydrogen content line. From Fig. 3 it is evident that a minimum of between 5 and 6 hr was necessary to reach equilibrium. This was an extreme case since the hydrogen content changed from less than 10 ppm to the highest value obtained, about 80 ppm.

Solubility of Hydrogen in Lime-Silica-Alumina Slags Equilibrated with Water Vapor-Nitrogen Atmospheres—Experiments were made with a 40 pct lime-40 pct silica-20 pct alumina composition at three temperatures, 1370°, 1450°, and 1550°C, and at six partial pressures of water vapor in nitrogen. The heats were held for a minimum of 6 hr, approaching equilibrium from both sides. The results are shown in Fig. 4, as the square root of the water vapor pressure (mm Hg) vs the hydrogen content (ppm). A straight line relationship was obtained which passed through the origin. This line is drawn through the points for the three temperatures and it is evident that there is no appreciable temperature coefficient of solubility for this slag.

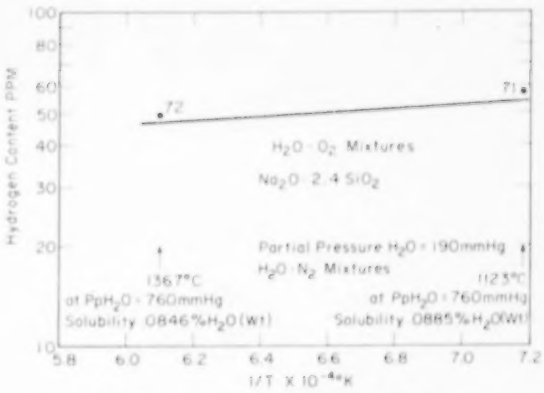

Fig. 6—Solubility of hydrogen in sodium silicate glass. Line is calculated from Russell.[11]

Solubility of Hydrogen in Lime-Silica-Alumina Slags Equilibrated with Hydrogen-Nitrogen-Water Vapor Atmospheres—With the same slag composition as above, the water vapor pressure in the atmosphere was held constant at 190 mm Hg (25 pct), with varying quantities of hydrogen diluting the nitrogen. In Fig. 5, the hydrogen content of the gas was plotted vs the analyzed hydrogen content of the slag. Within experimental error, the dissolved hydrogen was independent of the partial pressure of the hydrogen in the gas phase, and depended only on the partial pressure of water vapor present.

Dry mixtures of hydrogen and nitrogen gases were used to confirm this result. The hydrogen and nitrogen mixtures were purified to remove oxygen, water vapor, and CO_2. A gas mixture with a partial pressure of hydrogen of 190 mm Hg (25 pct) was equilibrated with a slag of the same composition as above, and was held in a molybdenum crucible. Nitrogen was used to flush the furnace tube while the molybdenum crucible was positioned in the furnace to minimize the formation of the volatile oxides of molybdenum. For the first heat of this group, see Table III, the crucible was held empty under the reducing atmosphere for 1 hr to remove oxygen dissolved in the molybdenum before charging the slag, but no difference from succeeding heats was noted. The solubility of hydrogen was found to range from 4 to 7 ppm and, while this could have been due to the hydrogen content of the gas, the small quantity dissolved could also be due to water vapor in the gas stream not removed by the purification. The solubility of hydrogen in this slag under a 25 pct water vapor-nitrogen mixture was 42 ppm, while under a 25 pct hydrogen in nitrogen mixture the solubility was probably less than 4 ppm.

Using the experimental technique developed in this investigation, it was possible to study the hydrogen solubility of glasses. Furthermore, a comparison with the work of Russell,[11] who used a different analytical method, was permitted.

A glass of the composition 30 pct silica and 70 pct soda, from the same batch as used by Russell, was equilibrated with a 25 pct water vapor in nitrogen mixture at two temperatures (1123° and 1367°C).

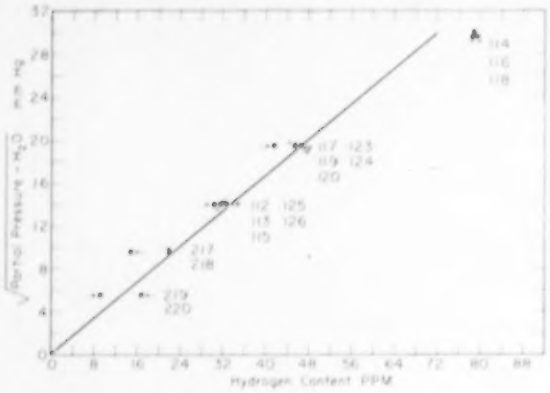

Fig. 7—Hydrogen solubility as a function of $p_{H_2O}^{1/2}$ in a 62 pct MnO-38 pct SiO_2 slag. Tests were run in water vapor-nitrogen mixtures. Circles represent 1350°C; crosses, 1450°C.

In Fig. 6 the results of this investigation are plotted together with the line calculated from Russell's data, and are found to agree within 5 pct. Soda was found to coat the furnace tube of the vacuum fusion equipment, which could lead to some uncertainty in the results. The slope of the curve indicated that the solubility of hydrogen decreased with increasing temperature.

Solubility of Hydrogen in Binary Lime-Silica Slags—Slags of compositions corresponding to lime saturation, silica saturation, and 50 pct CaO-50 pct SiO_2 were brought into equilibrium with pure steam at 1550°C. As Table IV shows, the solubility increases slightly with basicity, but the effect is small.

Solubility of Hydrogen in Manganese Silicates—The behavior of binary silicates containing a more reducible oxide than CaO was studied in the manganese silicate system. Slags of high silica content in the system may be contained in platinum crucibles without serious contamination of the platinum.

Slags containing 62 pct MnO and 38 pct SiO_2 were equilibrated with water vapor-nitrogen mixtures over the same range of partial pressures as used in the lime-silica-alumina system. Most of the data were obtained at 1350°C with a few heats at 1450°C. The slags were not glassy on quenching, and from 5 to 15 separate pieces were required for analysis. Again a straight line relationship between solubility of hydrogen and the square root of the water vapor pressure best described the results, Fig. 7. There was no appreciable temperature effect.

The slags were dark brown in color, presumably due to the presence of manganic (Mn^{+++}) ion. The effect of manganic ion on the hydrogen solubility is not known with certainty, but experiments with iron silicates at different oxygen pressures suggest that the effect is slight."

A comparison with binary lime silicates shows that at equimolar compositions (64 mol pct basic oxide) the manganese silicate has a slightly lower hydrogen solubility (65 ppm as against 75 ppm for the lime silicate; both slags equilibrated with pure steam). The effect is small but may be significant.

Solubility of Hydrogen in Other Slag Systems—A few heats were made in the MnO-CaO system to study the hydrogen content of a silica free slag. On quenching, the slags appeared puffed and porous, suggesting that gas had escaped. The hydrogen content was about 10 ppm under a pure steam atmosphere. On the addition of silica to these slags up to near silica saturation, with two different manganese oxide to lime ratios, the solubility of hydrogen approached but did not reach values in the lime-silica-alumina system (42 ppm at 25 pct H_2O).

Iron oxide slags were held in iron crucibles with the water vapor pressure held constant at 190 mm Hg. Hydrogen, which is not appreciably soluble in slags, was used to control the oxygen pressure to prevent reduction of iron oxide in the slag or, alternatively, oxidation of the crucibles. Again, in the iron oxide and iron oxide-lime systems, analyses indicated a low hydrogen content, while the addition of silica to iron oxide caused an increase (near silica saturation) to higher hydrogen contents. The values for the iron silicates, highest in silica content, were very close to those for comparable manganese silicates. Reproducibility of results was much poorer with the slags which contained little or no silica. This seems to be due in part to variable loss on quenching.

Table II. Analyses of Synthetic and Industrial Slags

	Hydrogen Content, Ppm		
	Actual	Mean	Range
Synthetic Slags, Composition, Pct			
40 CaO – 40 SiO_2 – 20 Al_2O_3	79.0		
	80.6		
	81.0	80.2	2.0
50 CaO – 50 SiO_2	79.5		
	79.1		
	78.6	79.0	1.1
62 MnO – 38 SiO_2	40.8		
	42.7	41.8	1.9
Industrial Slags			
Basic open hearth	28.2		
	35.0		
	34.6	32.6	6.8
Acid open hearth	10.6		
	14.8		
	12.7	12.7	4.2
Basic electric, oxidizing	20.5		
	24.4		
	19.1	21.3	5.3

Results from Industrial Heats

Both slag and steel were sampled for hydrogen during the course of industrial heats of basic and acid open hearth practice and from the oxidizing stage of basic electric practice.

Sampling and Handling—Most of the slag samples taken from industrial heats were obtained by taking a spoon sample out of the furnace and allowing the slag to cool on a steel plate. Experiments had shown that a rapid quench is not necessary to retain the slag hydrogen. When the slag had cooled

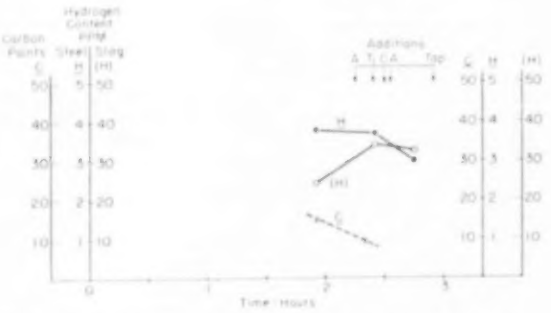

Fig. 8—Basic open hearth Heat No. 11. Additions: A, burnt lime; and C, liquid pig iron. T_i is 2790°F.

sufficiently to be handled conveniently (below 400°C) the sample was wrapped in a numbered sheet of aluminum foil and stored in a desiccator in the presence of a drying agent (Anhydrone). No attempt was made to analyze those slags which decompose in the atmosphere, or slags of the carbide type from the reducing stage of basic electric practice, which would be expected to absorb moisture from the atmosphere rapidly. The steel samples were obtained, stored, and analyzed as described by Epstein, Walsh, and King[4] and Chipman.[5]

Average Value of the Hydrogen Content of Basic Open Hearth Slags—Slag samples from basic open hearth heats of low carbon steel produced in large furnaces (200 tons capacity) were obtained a few minutes before tapping. Samples were obtained by pouring the spoon of slag onto a steel plate with an occasional duplicate onto a copper plate; no significant difference was found. These values, tabulated in Table V, range from 20 to 40 ppm with the mean value at 33 ppm. The purpose of taking these slag samples was to establish an average value for the slag hydrogen content for this practice (characterized by a strong boil) at a time in the refining practice which would give a basis for comparison with other heats.

Hydrogen in Basic Open Hearth Practice—Four basic open hearth heats (Nos. 11, 12, 19, and 20) were sampled for hydrogen in slag and steel virtually simultaneously during the refining period. These results, together with the carbon content, are plotted in Figs. 8 through 11. In Heats 11 and 12 the hydrogen content of the bath was somewhat lower than is normally found. Considerable variation occurred in the slag hydrogen content. Especially in Heats 19 and 20, where the initial slag samples were taken early in the flush slag stage, the hydrogen content of the slag gradually increased as the heat progressed. In all cases, the hydrogen content of the steel bath was reduced to its lowest value at some stage of the carbon boil at a time when the hydrogen content of the slag was tending to increase.

Slag-shaping additions did not seem to have an immediate effect on the slag hydrogen content during refining. It is possible that most of the water introduced with slag-shaping additions is lost to the furnace atmosphere as the addition dissolves into the slag. The final slag hydrogen content at tap in three of the heats was very close to the average value at tap as described in the preceding section.

Hydrogen in Acid Open Hearth Practice—The hydrogen contents of the slag and steel bath were measured during the course of three acid open

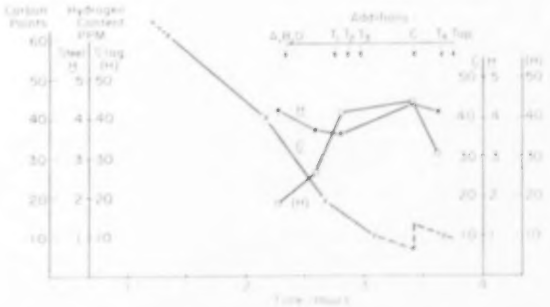

Fig. 9—Basic open hearth Heat No. 12. Additions: *A*, burnt lime; *B*, ore; *C*, liquid pig iron; and *D*, fluorspar. T_1, T_2, and T_3 are 2800°; T_4 is 2860°F.

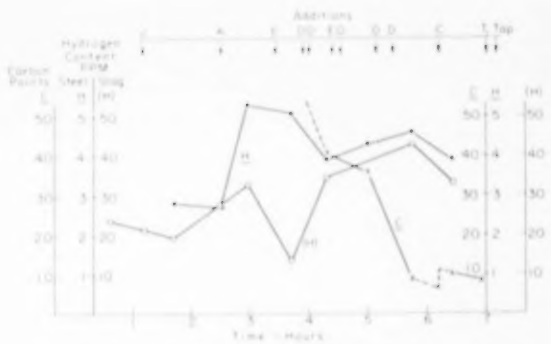

Fig. 10—Basic open hearth Heat No. 19. Additions: *C*, liquid pig iron; *D*, fluorspar; *E*, limestone; *J*, end flush slag; and *K*, start lime boil. T_1 is 2840°F.

hearth heats, Nos. 13, 14, and 15, shown in Figs. 12 through 14. Heats 14 and 15 were fired by air-atomized fuel oil while the oil used in Heat 13 was steam-atomized. The hydrogen content of the slag throughout Heat 13 was lower than that found in the other two heats, with the general level of the three acid slag contents about one third that of the basic slags of the previous section. There was no large variation of the slag hydrogen content during the course of any heat.

Heat 14 was held for 31 min after blocking with ferrosilicon, with no appreciable change of hydrogen content occurring in either slag or steel. This is in contrast with the behavior of a basic heat held in the furnace for 27 min after blocking, where it was found that the bath hydrogen increased at a rate of 6 ppm per hr.[5, 10]

Hydrogen in Basic Electric Furnace Practice—The hydrogen and carbon contents of two basic electric furnace heats were obtained during the oxidizing stage (Heats 16 and 21, shown in Figs. 15 and

Table III. 40 Pct CaO-40 Pct SiO_2-20 Pct Al_2O_3 Slag Equilibrated with 25 Pct H_2-75 Pct N_2 Gas Mixture

Time of Equilibration at 1370°C	Slag Hydrogen Content, Ppm	
	Actual	Mean
4 Hr	6.1	7.3
	8.4	
6 Hr	7.1	7.7
	8.3	
7 Hr	4.9	4.6
	4.3	

16). Heat 16 was characterized by a strong carbon boil which was reflected in the low hydrogen content of the steel bath. In contrast to the basic open hearth heats, there was no indication of a gradual rise in the slag hydrogen content. In fact, in Heat 16, there appeared to be a definite drop, whereas in Heat 21, there appeared to be no appreciable change.

Two other heats were sampled just before slag-off. In Heat 17 the slag and bath hydrogen contents were 15.5 and 2.6 ppm respectively, and in Heat 18, 7.3 and 1.7 ppm, indicating that low values in slag and bath could be obtained in the oxidizing stage of basic electric practice.

Equilibrium of Industrial Slags with a Water Vapor-Nitrogen Atmosphere—Four of the slags from acid Heat 15 and two from basic Heat 19 were equilibrated with a 25 pct water vapor in nitrogen

atmosphere at 1550°C for a period of at least 6 hr, see Table VI. The hydrogen content of the acid slags was found to increase by a factor of about three. Of the basic slags selected, one had a normal hydrogen content and the other was abnormally low. Both increased to a value higher than that of the acid slags. The appearance of the acid slags after quenching from the test temperature indicated that not all of the slag had melted. This may have been due to the change in composition resulting from the higher oxygen pressure of this atmosphere, as compared to the value in equilibrium with the slag composition in the furnace. Consequently, the acid slags may not have reached equilibrium, due to their high viscosity.

It seems likely that in the open hearth furnace the hydrogen content of acid slags is further from equilibrium with respect to the water vapor content of the furnace atmosphere than is the hydrogen content of basic slags. Furthermore, the hydrogen content of the acid slags was found to remain nearly constant in the furnace while that of basic slags varied widely. The highest value found for basic slags in this investigation was 45 ppm, in Heat 20. This value compares closely with an equilibrium hydrogen solubility in the lime-silica-alumina system of 42 ppm under a 25 pct water vapor in nitrogen atmosphere.

Discussion

Synthetic Slag Studies—The straight-line relationship between $p_{H_2O}^{1/2}$ and solubility of hydrogen found for the synthetic slags shows that water does not dissolve molecularly in slags nor, according to Russell,[11] in glasses. It is not possible to suggest, from these results alone, the form of the dissolved hydrogen. Either of the following equations would be in accord with such a result.

$$H_2O + O^{=} = 2\,OH^{-}$$
$$H_2O = 2H^{+} + O^{=}.$$

In view of the small size of the hydrogen ion it would not seem reasonable to expect protons to exist as such, but hydrogen bonding in which protons resonate between two oxygen ions remains a distinct possibility.

The effect of basicity in the lime-silica system is not in accord with the observation that slags containing little or no silica dissolve very little water, and these results are not helpful in a structural interpretation. Other experimental work is necessary to develop further information.

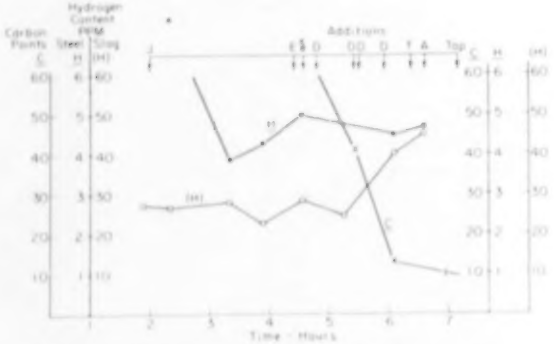

Fig. 11—Basic open hearth Heat No. 20. Additions: *A*, burnt lime; *B*, ore; *D*, fluorspar; *E*, limestone; and *J*, end flush slag. *T* is 2795°F.

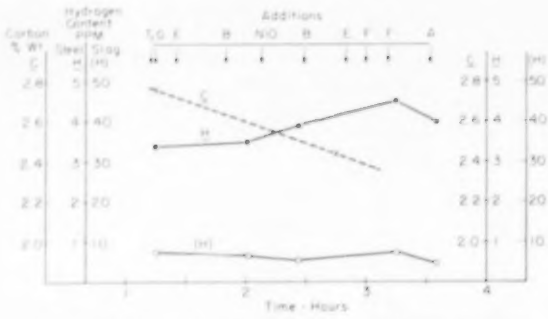

Fig. 12—Acid open hearth Heat No. 13. Additions: *A*, burnt lime; *B*, ore; *E*, limestone; *F*, sand; and *G*, —FeO = 33.7 pct. *T*, is 2750°F.

Industrial Heats—The number of heats from each type of practice is not large, but the behavior of the steel hydrogen content is typical and there is no reason to suspect that the slag samples are not representative. The following discussion is generalized from these heats and from the much larger accumulation of data in the literature on the variation of hydrogen content of steel during a heat.

The hydrogen content of basic slags rises during a heat and has a mean value of about 30 ppm; the hydrogen content of acid slags is about 10 ppm and remains approximately constant; the hydrogen content of basic electric slags seems to decline during the oxidizing period and has a mean value of about 20 ppm.

In fuel-fired furnaces the gases contain about 20 pct water vapor, so that the equilibrium hydrogen content of open hearth slags should be about 40 ppm.

Table IV. Variation of Hydrogen Solubility with Variation of Composition in the Lime-Silica System

Composition, Pct	Average Hydrogen Content under Steam Atmosphere at 1500°C, Ppm
67 SiO_2—33 CaO (silica saturation)	74.3
50 SiO_2—50 CaO	82.9
43 SiO_2—57 CaO (lime saturation)	85.1

Basic slags approach this value toward the end of the heat but acid slags do not. The experiments of Table VI show that equilibrium can be reached in the laboratory. Presumably, in practice, the high viscosity of the acid slag, combined with the poorer stirring resulting from lower boil rates, results in a much slower transfer rate of hydrogen from gas to slag than in the basic open hearth. Some tentative laboratory experiments on gas-slag transfer support this conclusion. In the basic electric furnace the slag is much closer to equilibrium with the furnace atmosphere. Depending on the humidity of the air, the atmosphere may contain 0.3 to 5.0 pct water vapor. The corresponding equilibrium slag hydrogen contents are about 6 to 20 ppm. However, gas-slag transfer is complicated by slag-metal transfer. Thus, in the acid open hearth furnace, the constancy of the hydrogen content of the slag is to be taken as an indication that water is being absorbed by the slag from the atmosphere at the same rate as hydrogen is being transferred to the steel from the slag.

As has been suggested by many authors[1-6, 7] and demonstrated conclusively by Kalling and Rudberg,[16] the carbon boil gases remove hydrogen from the

Table V. Hydrogen Content of Slags Sampled from Basic Open Hearth Furnaces at Tap

Heat No.	Carbon, Approximate Pct	Time from Last Addition, Min		Hydrogen Content of Slag, Ppm	Mean Ppm	Sample Poured On Metal Plate
		To Slag	Oxygen			
1	0.04	42 (ore)	2	(31.9, 34.9, 36.1)	34.3	Steel
2	0.07	82 (ore)	None	(26, 3, 34.1)	30.2	Copper
3	0.05	55 (ore)	30	(27.8, 27.4)	27.4	Steel
4	0.06	32 (burnt lime)	8	(42.0, 45.0)	43.5	Steel
5	0.04	27 (Mn)	37	(31.3, 35.9, 33.0)	33.4	Steel
6	0.05	28 (ore)	8	(35.3, 38.2)	36.7	Steel
7	0.05	37 (ore)	1	(35.6, 36.6)	36.1	Steel
8	0.04	36 (ore + Mn)	11	(35.9, 36.4, 40.2)	38.2	Copper
				(35.8, 30.8, 35.5)	34.0	Steel
9	0.03	38 (ore)	8	(32.4)	32.4	Copper
				(31.1, 28.2)	29.7	Steel
10	0.04	99 (raw lime + ore)	1	(26.4, 25.7)	25.0	Copper
				(23.9, 24.6)	24.3	

Average hydrogen content—33 ppm

steel by the so-called flushing action. Epstein, Walsh, and King,[4] assuming that the escaping gases reached equilibrium with the hydrogen content of the steel, derived the following expression

$$-\frac{d(\text{ppm})}{dt} = K \cdot (\text{ppm})^x \frac{dC}{dt}$$

where $-d(\text{ppm})/dt$ is the rate of decrease in hydrogen content (ppm per hr), dC/dt is the boil rate (points carbon per hr), ppm is the hydrogen content of the steel at time t, and the constant K depends on the equilibrium solubility of hydrogen in the steel and the units used. In practice the hydrogen content of the steel may increase, decrease, or remain approximately constant during the boil depending upon both the practice and the boil rate. As Epstein[16] has shown, this behavior can be explained if hydrogen is being supplied from or through the slag to the steel at a rate which is also dependent on the boil rate.

In basic practice the gas-slag transfer rate may be higher than the slag-metal transfer rate, though the contribution of slag-shaping additions such as moist ore should not be neglected. In acid furnaces the gas-slag transfer rate is approximately equal to the slag-metal transfer rate and is much lower than in basic furnaces, since it is possible to reach similar metal hydrogen contents at lower boil rates.

In basic electric practice the slag viscosity is similar to that of basic open hearth slags. The slag-metal transfer rate is, to judge by the boil rates necessary to reach a certain hydrogen content in the metal, intermediate between that of the acid and basic open hearth furnaces. It is possible that the decline in hydrogen content of the slag during a heat is partly the result of a slag to metal transfer, the slag acting as a reservoir. Depending on the atmospheric humidity, the slag may also lose hydrogen to the atmosphere, or gain from the atmosphere.

In all cases the boil gases may also tend to flush hydrogen from the slag. This may be the reason for the occasional decreases in hydrogen content, observed in Heats 11, 12, and 19 after a liquid pig iron addition was made, causing a short but intense boil. In view of the small slag depth it is unlikely that the process will be very efficient, and this possibility does not affect the above qualitative conclusions. It should also be noted that increased boil rates, by increased convection, will increase the rates of gas-slag and slag-metal transfer as well as the rate of removal of hydrogen from the metal. The effect will be less with acid slags because of their higher viscosity, as may be shown by reference to the blocked acid Heat No. 16. Neither the slag nor steel showed any increase in hydrogen content after blocking, yet an appreciable transfer rate from gas to slag to steel must exist during the boil since the metal hydrogen content does not continue to fall.

Quantitative conclusions are probably not justified at the present time. It is of interest that Dobrokhotov, Povolskii, and Khan[18] have suggested that thickening agents, such as heavy limestone additions to basic slags, might reduce the hydrogen input rate and enable lower hydrogen steels to be produced at the same boil rates, or afford greater protection to the steel after furnace blocking.

The potentially favorable position of the electric furnace when atmospheric humidity is low might be realized by using slag-making constituents, even for oxidizing slags, which have been carefully dried. The acid furnace does not have a favorable atmosphere but the initial slag hydrogen content is low, since essentially no lime is added in the beginning, and hydrogen does not transfer rapidly to the steel from an acid slag. Hence the acid furnace is capable of producing very low hydrogen steel.

Conclusions

Analyses of synthetic and industrial slags for hydrogen by an adaptation of the technique used for steels lead to the following conclusions:

1) The solubility of hydrogen in synthetic slags is proportional to the square root of the partial pressure of water vapor in the atmosphere in contact with the slags.

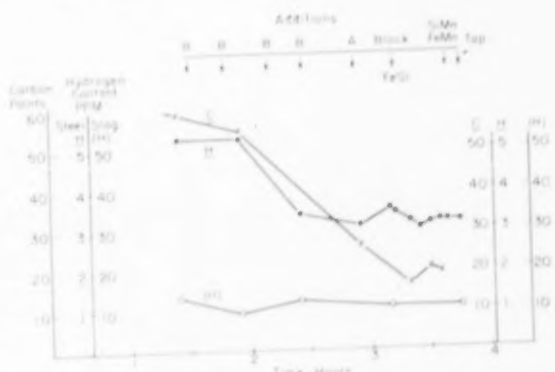

Fig. 13—Acid open hearth Heat No. 14. Additions: *A*, burnt lime; and *B*, ore. This heat was held under block for 31 min.

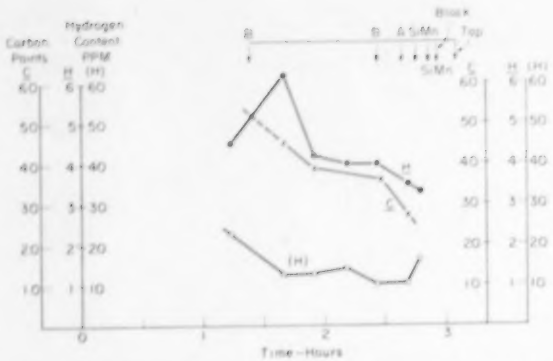

Fig. 14—Acid open hearth Heat No. 15. Additions: *A*, burnt lime; and *B*, ore.

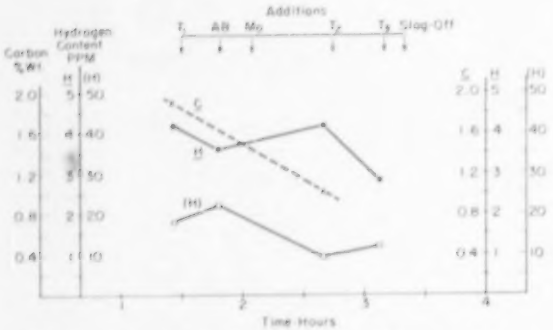

Fig. 15—Basic electric Heat No. 16. Additions: *A*, burnt lime; and *B*, ore. Oxidizing stage only. T_1 is 2870°; T_2, 2860°; and T_3, 2910°F.

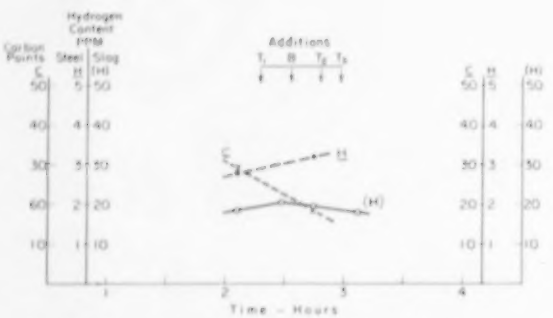

Fig. 16—Basic electric Heat No. 21. Addition: *B*, ore. Oxidizing stage only. T_1 is 2940°; T_2, 2890°; and T_3, 3000°F.

2) Hydrogen in slags results from reaction of the slag with water vapor; slags do not dissolve significant amounts of hydrogen from hydrogen gas.

3) Within the ranges encountered in practice, temperature and slag composition have minor effects on the solubility.

4) Acid open hearth slags contain less hydrogen in practice than basic open hearth slags. In addition, the hydrogen content of acid slags remains far from equilibrium with the furnace atmosphere during a heat. With basic slags the hydrogen content of the slag rises during a heat to almost the equilibrium value at tap.

5) Basic electric slags are closer to equilibrium with the furnace atmosphere, and the hydrogen content can decline during a heat.

6) In all practices the slag is not at equilibrium with the steel but the carbon boil prevents the hydrogen content of the steel from rising.

7) Acid slags pick up hydrogen from the atmosphere and transfer hydrogen to the steel at lower rates than basic slags. This is probably to be attributed to the higher viscosity of acid slags.

Table VI. Equilibration of Open Hearth Slags with Water Vapor-Nitrogen Gas Mixtures

Hydrogen Content in Open Hearth, Ppm			Hydrogen Content after Equilibration, Ppm	
Analyses	Mean	Equilibration Time,* Hr	Analyses	Mean
Acid Open Hearth Slags from Heat No. 15				
(13.5, 14.5)	14.0	5.2	(31.4, 32.6)	32.1
(10.4, 10.1)	10.3	6.0	(32.4, 36.5)	34.5
		6.0	(26.6, 29.0)	28.8
(9.9, 10.8)	10.4	14.7	(39.0, 39.9)	39.5
(16.1, 16.9)	16.6	10.7	(28.5, 29.6)	29.1
Basic Open Hearth Slags from Heat No. 19				
(27.7, 27.4)	27.6	6.0	(45.7, 46.2)	46.0
(14.6, 13.0)	13.8	6.0	(46.6, 45.4)	46.0

* At p_{H_2O} = 190 mm Hg.

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References

[1] H. Wentrup, H. Fucke, and O. Rief: Hydrogen Contents of Liquid Steel Melted by Different Processes. *Stahl und Eisen*, 1949, vol. 69, p. 117. Brutcher translation No. 2282.

[2] E. Piper, H. Hagedorn, and H. Backes: Behavior of Hydrogen in Steelmaking. *Stahl und Eisen*, 1955, vol. 76, p. 817. Brutcher translation No. 3235.

[3] K. C. Barraclough: The Significance of Hydrogen in Steel Manufacture. *Murex Review*, 1954, vol. 1, p. 305.

[4] H. Epstein, J. H. Walsh, and T. B. King: Hydrogen in Steelmaking. *Regional Technical Meetings* AISI, 1954, pp. 25-46.

[5] J. Chipman: Hydrogen in Steelmaking. *Jernkontorets Annaler*, 1955, vol. 139.

[6] B. Shields, J. Chipman, and N. J. Grant: Thermal Conductivity Method for Analysis of Hydrogen in Steel. *AIME Trans.*, 1953, vol. 197, p. 180; Journal of Metals, February 1953.

[7] S. von Hofsten, B. Kalling, F. Johansson, and O. V. Knös: Absorption and Evolution of Hydrogen During Steelmaking. *Jernkontorets Annaler*, 1939, vol. 123, p. 485.

[8] R. W. Goranson: *Amer. Geophysical Union*, 1936, vol. 17, p. 257.

[9] R. H. Dalton: Extraction and Analysis of Gases from Glass. *Journal* ACS, 1935, vol. 57, p. 2150.

[10] H. Salmang and A. Becker: Gases in Glass. *Glastechnische Berichte*, 1927-1928, vol. 5, p. 520.

[11] L. E. Russell: Solubility of Water in Molten Glass. Sc.D. Thesis, Massachusetts Institute of Technology, 1955.

[12] V. L. Yavoiskii: Transfer of Gases to Metal Through Slag. *Stal*, 1947, vol. 7, pp. 796-807.

[13] N. H. Dobrokhotov, D. Y. Povoloskii, and Kh. T. Kahn: Transfer of Gases to Metal Through Slag. *Inst. Chemoi. Met. Akad. Navi* SSR, 1953, pp. 23-32.

[14] I. M. Kolthoff and E. B. Sandell: *Text Book of Quantitative Inorganic Analysis*, pp. 131 ff. New York. MacMillan Co., 1947.

[15] H. Larson and J. Chipman: Oxygen Activity in Iron Oxide Slags. *AIME Trans.*, 1953, vol. 197, p. 1089; Journal of Metals, September 1953.

[16] H. Epstein: Hydrogen in Steelmaking. Sc.D. Thesis, Massachusetts Institute of Technology, 1955.

[17] B. M. Mullin: Unpublished work, Massachusetts Institute of Technology, 1955.

[18] B. Kalling and M. Rudberg: Investigation of the Composition of Boil Gases in Steelmaking. *Jernkontorets Annaler*, 1938, vol. 122, p. 91.

Discussion of this paper sent (2 copies) to AIME by Jan. 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957, and in Journal of Metals, October 1957.

Self-Diffusion of Iron in Molten Fe-C Alloys

Self-diffusion coefficients of iron in molten Fe-C alloys have been measured by using the capillary method. In addition, the samples have been autoradiographed and sectioned to insure that no significant convection has occurred during the diffusion. The results can be represented by the equation $D = 4.3 \times 10^{-4} \exp(-12{,}200/RT)$ for carbon = 4.6 pct and $T = 1513°$ to 1633°K; and $D = 1.0 \times 10^{-4} \exp(-15{,}700/RT)$ for carbon = 2.5 pct and $T = 1613°$ to 1673°K. The D values are higher and the heat of activation for diffusion lower in alloys containing more carbon. Calculation based on the Einstein-Stokes equation indicates that the diffusing species is iron ion.

by Ling Yang, M. T. Simnad, and G. Derge

STUDY of diffusion in molten substances is important in at least two respects. Diffusion data, combined with thermodynamic and kinetic information, throw light on the structure of the liquid state. Moreover, a knowledge of diffusion coefficients and their temperature dependence is useful in ascertaining the controlling step in many metallurgical reactions. Although diffusion measurements have been made on a number of molten salts, slags, metals, and alloys,[1-10] the results available are still limited and widely scattered, especially for the high temperature melts. It is the purpose of this investigation to establish reliable procedures for the measurement of self-diffusion coefficients in high temperature melts and to use these procedures to determine the self-diffusion coefficients of iron in molten Fe-C alloys of different carbon contents.

Experimental

Measurement of self-diffusion coefficients in high temperature melts is usually carried out by using one of two methods. In the first, diffusion takes place between two cylindrical samples of the same material, one of which is made radioactive. The diffusion coefficient is calculated from the radioactivity penetration curve in the solidified sample after the diffusion. In the second method, samples contained in capillaries of an inert substance are immersed in an infinite reservoir of the same material. Either the material in the capillary or that in the reservoir is made radioactive and the diffusion coefficient is calculated from the change of the radioactivity of the sample in the capillary after the diffusion. The second method is simpler because a radioactivity penetration curve is not needed for the calculation of the diffusion coefficient; however, it is valid only when no convection has occurred in the capillary during the diffusion. A radioactivity penetration curve is therefore always useful in indicating that the required conditions for the diffusion are fulfilled. Towers and Chipman[11] recently studied the self-diffusion of calcium and silicon in CaO-Al_2O_3-SiO_2 melts by using the capillary method. Instead of measuring the change of the radioactivity of the sample in the capillary, they autoradiographed the sample after the diffusion and calculated the diffusion coefficient from the intensity distribution of the autoradiograph. Their method is useful when the radioactive isotopes are weak β-emitters, but is very difficult, if not impossible, to apply to cases involving strong β or γ-emitters. For such cases, sectioning of the sample according to the method of Morgan and Kitchener[7] may be used for the construction of the radioactivity penetration curve. The self-diffusion of iron in molten Fe-C alloys has been studied in this manner and the experimental procedures are described as follows:

The diffusion apparatus is shown schematically in Fig. 1. The bath consisted of about 200 g of an Fe-C

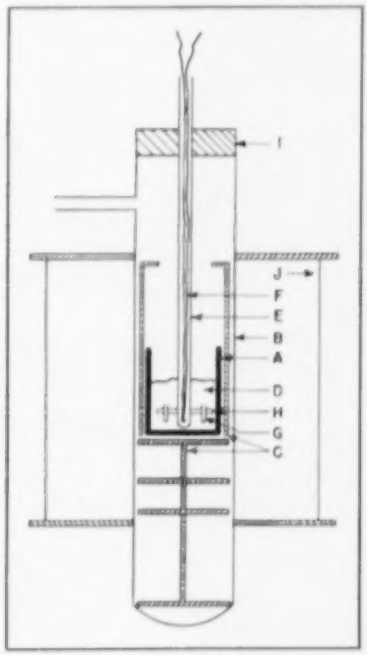

Fig. 1—Experimental arrangement for measuring the self-diffusion coefficient of iron in molten Fe-C alloy. Letters represent: *A*, McDanel crucible; *B*, McDanel jacket; *C*, graphite shields, *D*, molten Fe-C alloy; *E*, McDanel sample holder; *F*, Pt—Pt-10 pct Rh thermocouple; *G*, fused Alundum capillary; *H*, zircon disk; *I*, rubber vacuum seal; and *J*, Globar furnace.

LING YANG, M. T. SIMNAD, and G. DERGE, Members AIME, are Research Metallurgical Engineer, Senior Research Metallurgical Engineer, and Jones & Laughlin Professor of Metallurgy, respectively, Metals Research Laboratory, Dept. of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh.

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Fig. 2—Some autoradiographs of samples after diffusion.

alloy of the desired composition in a McDanel crucible (4 in. tall and 1 in. ID). The specified alloy was made by melting Plast-iron (0.018 pct C, 0.070 pct O, and less than 0.05 pct other impurities) in a graphite crucible and adding this carbon-saturated alloy to the necessary amount of Plast-iron. The crucible was surrounded with graphite shields inside a McDanel jacket and was heated by a Globar furnace. The temperature gradient in the molten alloy was found to be negligible and the change of bath temperature during a diffusion period of about 1 hr was less than ±2°C. The specimen holder was a McDanel thermocouple protection tube (⅜ in. OD, one end closed) with a zircon disk (⅛ in. thick, ¾ in. diam) cemented to it with Alundum cement. Holes were drilled in the zircon disk to accommodate four fused Alundum capillaries of 0.050 in. (±2 pct) or 0.065 in. (±2 pct) ID and about ½ to ⅝ in. in length. These capillaries were sealed at one end with an oxygen torch and cemented to the zircon disk with Alundum cement. Temperature of the bath was measured with a Pt—Pt-10 pct Rh thermocouple in the McDanel thermocouple well.

After the alloy in the McDanel crucible was melted and thoroughly degassed in vacuum (10^{-4} mm Hg), the sample holder was lowered gradually into the melt through the rubber vacuum seal at the top of the McDanel vacuum jacket. Argon was then admitted into the system to push the liquid alloy into the fused Alundum capillaries. The filling of the capillaries was always done at the same temperature as that used in the diffusion run, and the latter was always above that of the liquidus of the alloy in the bath so that no solid phase separated out to hinder the diffusion. After the capillaries were filled, the sample holder was slowly raised out of the melt to the upper part of the McDanel jacket and cooled in argon. The filled capillaries were then separated from the zircon disk and their open ends polished on emery paper until the metal rods appeared. This was necessary in order to insure a good contact between the sample in the capillaries and the melt in the bath during the diffusion run. The filled capillaries were cemented to a new zircon disk on the sample holder and were ready for the diffusion run.

Before the diffusion run, the molten alloy in the bath was made radioactive by dropping into it a small Armco iron capsule containing the radioactive Fe^{59} and the necessary amount of graphite powder to maintain the bath composition. After the bath was homogenized in vacuum, a capillary sample was taken as described previously and used to determine the initial specific radioactivity c_o of the bath. This was a few thousand counts per minute per gram. The diffusion was then carried out by first holding the capillaries in vacuum in the upper part of the McDanel jacket to remove any adsorbed gas and then lowering them slowly into the diffusion bath in a purified argon atmosphere. After a predetermined period of time, the capillaries were quickly raised out of the bath to the upper part of the McDanel tube and cooled in argon. Care was taken to avoid any mechanical vibration of the system during the diffusion. Stirring of the bath by rotating the specimen holder once every few minutes did not affect the results significantly. The same bath could be used for four or five runs with negligible change in carbon content and specific radioactivity.

After the diffusion run, the metal rods were separated by cracking the alumina capillaries with a small hammer. They were then weighed on an analytical balance and their lengths measured with a micrometer. The radioactivity gained by diffusion was determined with a Geiger counter, using a TGC-2 tube. The self-diffusion coefficient was then calculated by the equation

$$\frac{\bar{c}}{c_o} = 1 - \frac{8}{\pi^2}\left(e^{-\theta} + \frac{1}{9}e^{-9\theta} + \frac{1}{25}e^{-25\theta} + \ldots\ldots\right) \qquad [1]$$

where $\bar{c}$ is the average specific radioactivity of the metal rod after diffusion; c_o is the specific radioactivity of the molten alloy in the bath; and $\theta = \left(\frac{\pi^2 Dt}{4l^2}\right)$; D being the self-diffusion coefficient; t, the time of diffusion in seconds; and l, the length of the capillary in centimeters, evaluated from the length of the metal rod corrected for its contraction due to solidification and temperature change. To facilitate the calculation, the equation was plotted in the form of Dt/l^2 against $\bar{c}/c_o$. The Dt/l^2 values corresponding to the experimental $\bar{c}/c_o$ values were read from this curve and the D values calculated from the corresponding t and l values. To make sure that no significant amount of convection or other disturbances to diffusion had occurred during the run, autoradiographs of all samples were taken, Fig. 2,

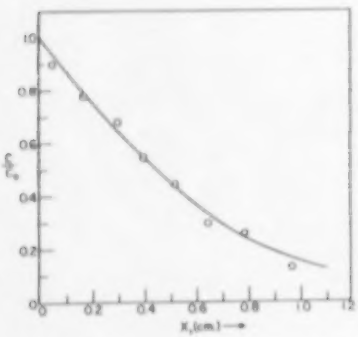

Fig. 3—Radioactivity distribution in sample after diffusion as compared with the calculated distribution. Curve was calculated from Eq. 2 where $l = 1.22$ cm, $D = 9.6 \times 10^{-5}$ sq cm per sec, and $t = 2160$ sec. Points were obtained experimentally by sectioning the sample.

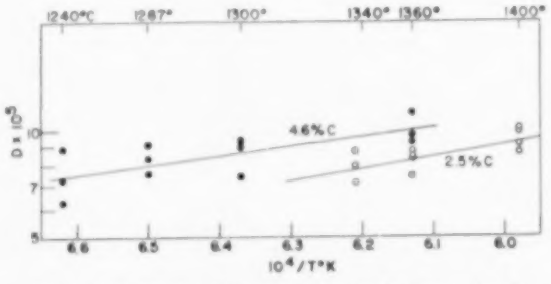

Fig. 4—Self-diffusion of iron in molten Fe-C alloys as log D vs $10^4/T°K$.

Table I. Self-Diffusion Data for Iron in Molten Fe-C Alloys

Carbon, Wt Pct	Diffusion Temperature, °K	Length of Capillary, Cm	Diffusion Time, Sec	Average Specific Activity c of Sample After Diffusion, Cpm per G	Specific Activity c_0 of Bath, Cpm per G	$D \times 10^5$, Sq Cm per Sec
4.6	1513	1.41	1920	626	2244	6.3
4.6*	1513	1.40	1800	927	2872	8.9
4.6*	1513	1.48	1800	788	2872	7.2
4.6*	1540	1.50	1800	800	2872	7.6
4.6	1540	1.51	2400	1082	3250	8.3
4.6	1540	1.42	2400	1208	3250	9.1
4.6	1573	1.45	1500	734	2520	9.3
4.6	1573	1.26	1500	820	2520	8.8
4.6	1573	1.42	2400	1016	3034	7.4
4.6	1633	1.52	2160	1250	3456	11.0
4.6	1633	1.22	2160	1460	3456	9.6
4.6	1633	1.40	1800	1000	3034	9.2
2.5	1613	1.42	1800	954	3034	8.7
2.5	1613	1.47	1800	880	3034	7.9
2.5	1613	1.37	3000	1142	3034	7.0
2.5	1633	1.52	1800	927	3150	8.7
2.5	1633	1.38	1200	816	3150	8.4
2.5	1633	1.45	1800	945	3150	8.3
2.5	1633	1.20	1200	882	3150	7.4
2.5	1673	1.25	1200	972	3150	9.7
2.5	1673	1.28	1800	1184	3150	10.1
2.5*	1673	1.40	1200	894	3450	8.6
2.5*	1673	1.38	1200	928	3450	9.0

* Capillary diameter 0.065±2 pct; the rest 0.050±2 pct.

and those rods yielding abnormal intensity distributions were discarded. The good rods were then cut into about 1 mm pieces which were weighed and dissolved in aqua regia. The solution from each piece was spread on a Pyrex planchet, dried slowly, and counted. From the counting results, a $(c/c_0) \sim x$ curve was constructed, Fig. 3, c being the mean specific radioactivity of each piece; c_0, the specific radioactivity of the molten alloy in the bath, determined in the same manner from a sample of about the same weight as that of the sectioned pieces; and x, the distance between the center of each piece and the open end of the capillary. A run was considered good if $c/c_0 \sim 1$ (within ±5 pct) when the curve was extrapolated to $x = 0$ and if the experimental points fell within ±0.1 unit on the c/c_0 axis to the theoretical curve calculated from the equation

$$\frac{c}{c_0} = 1 - \frac{4}{\pi}\left(\sin\left(\frac{\pi x}{2l}\right)e^{-\theta} + \frac{1}{3}\sin\left(\frac{3\pi x}{2l}\right)e^{-9\theta} + \dots\right) \quad [2]$$

where $\theta = \frac{\pi^2 Dt}{4l^2}$, D being the diffusion coefficient calculated by using Eq. 1. In these ways, nearly 50 pct of the runs were disqualified. The results from the good runs are shown in Table I and plotted in Fig. 4 as log D against $1/T$. The equations for the experimental lines are

$D = 4.3\text{x}10^{-4} \exp(-12{,}200/RT)$ for carbon = 4.6 pct

$D = 1.0\text{x}10^{-3} \exp(-15{,}700/RT)$ for carbon = 2.5 pct.

Discussion

The results indicate that the self-diffusion coefficient of iron is greater in molten Fe-C alloys of higher carbon content. The heat of activation for diffusion is slightly higher in melts of lower carbon content. It is known[16, 17] that carbon also decreases the heat of activation for diffusion and increases the diffusivity of iron in austenite. Although the observed effect of carbon in liquid alloys is much smaller than that in austenite, it is of interest to see that this *lattice loosening* effect of carbon persists in the liquid. The weakening of the interatomic force in austenite by carbon is also borne out by the observation[18] that carbon increases the vapor pressure of iron over austenite and decreases the heat of sublimation, although no corresponding work has been done for the liquid alloys.

The Einstein-Stokes equation, $D = kT/6\pi\eta r$, though derived under the assumption that the diffusing particles are very large compared with that of the medium, has been found to correlate fairly well the diffusivity D, the viscosity η, and the ionic radius r of the diffusing species in the case of diffusion of a number of metals in their amalgams,[7] the self-diffusion of mercury in liquid mercury,[6] sodium in liquid sodium,[8] and gallium in liquid gallium.[10] By using D values interpolated from the line for the 2.5 pct C alloy in Fig. 4 and the viscosity data for the 2.5 pct C alloy[15] (26.5 millipoise at 1350°C and 22.5 millipoise at 1400°C), the r values calculated are 0.57 and 0.59A for 1350° and 1400°C, respectively, as compared to r = 0.75A for Fe^{++}, 0.60A for Fe^{+++}, and 1.26A for iron atom. However, if the Eyring equation for monoatomic liquids, $D = kT/2r\eta$, is applied to the present case, the calculated r values are 5.4 and 5.6A for 1350° and 1400°C, respectively. Thus, while the r values calculated from the Eyring equation suggest a large complex as the diffusing species, those calculated from the Einstein-Stokes equation indicate an ionic form of iron as the diffusing species. This seems to be in agreement with the suggestion[19] that in liquid metal, the unit of diffusion is the ion rather than the atom, which has found support in the self-diffusion of mercury, sodium, and gallium in their liquid state. There does not appear to be an entirely satisfactory understanding of this problem.

Summary

The self-diffusion coefficient, D, of iron in molten Fe-C alloys can be represented by the equations: $D = 4.3\text{x}10^{-4} \exp(-12{,}200/RT)$ for carbon = 4.6 pct in the temperature range 1513° to 1633°K, and $D = 1.0\text{x}10^{-3} \exp(-15{,}700/RT)$ for carbon = 2.5 pct in the temperature range 1613° to 1673°K. The radius of the diffusing species calculated by using the Einstein-Stokes equation suggests that the diffusing species is ionic iron.

Acknowledgment

This work has been part of a research program sponsored by the AEC.

References

[1] J. Groh and G. von Hevesy: *Annalen der Physik*, 1932, vol. 20, p. 1567.
[2] W. F. Holbrook, C. C. Furnas, and T. L. Joseph: *Industrial and Engineering Chemistry*, 1932, vol. 24, p. 993.
[3] B. V. Stark, E. V. Shchilishchev, and E. A. Kazachev: *Izvestia Akad. Nauk, SSSR Otdel, Tekh. Nauk*, 1951, vol. 11, p. 1689.
[4] R. E. Hoffman: *Journal of Chemical Physics*, 1952, vol. 20, p. 1567.
[5] H. Towers, M. Paris, and J. Chipman: *AIME Trans.*, 1953, vol. 197, p. 1445; JOURNAL OF METALS, November 1953.
[6] G. Carert and A. Paoletti: *Il Nuovo Cimento*, 1954, vol. 10, p. 399.
[7] D. W. Morgan and J. A. Kitchener: *Trans. Faraday Soc.*, 1954, vol. 50, p. 51.
[8] R. Grace and G. Derge: *AIME Trans.*, 1955, vol. 203, p. 839; JOURNAL OF METALS, July 1955.
[9] R. Meyer and N. H. Nachtrieb: *Journal of Chemical Physics*, 1955, vol. 23, p. 405.
[10] S. J. Rothman and L. D. Hall: *AIME Trans.*, 1956, vol. 206, p. 199; JOURNAL OF METALS, February 1956.
[11] H. Towers and J. Chipman: Presented at AIME Annual Meeting, New York, February 1956.
[12] W. Jost: *Diffusion*. 1952, pp. 478-479. New York. Academic Press.
[13] J. Petit and N. H. Nachtrieb: *Journal of Chemical Physics*, 1956, vol. 24, p. 1027.
[14] H. Mead and C. E. Birchenall: Private communication.
[15] A Wimmer and Von H. Thielmann: *Stahl und Eisen*, 1927, vol. 47, p. 389.
[16] R. H. Ewell and H. Eyring: *Journal of Chemical Physics*, 1937, vol. 5, p. 726.
[17] P. L. Gruzin, Y. V. Kornev, and G. V. Kurdynmov: *Doklady A.N. SSSR*, 1951, vol. 80, No. 1, p. 49.
[18] Y. V. Kornev and V. N. Golubkin: *Doklady A.N. SSSR*, 1954, vol. 99, No. 4, p. 565.

Discussion of this paper sent (2 copies) to AIME by May 1, 1957 will appear in AIME *Transactions* Vol. 209, 1957, and in JOURNAL OF METALS, October 1957.

Technical Note

Diffusion in a Molten Bi-0.255 Atomic Pct Pb Alloy

by S. J. Rothman and L. D. Hall

Table I. Diffusion Coefficients

Run	Capillary	Temperature, °C	Time, Sec	*L*, Cm	Diameter of Capillary, Mm	Pb, *D*, Sq Cm per Sec x 10^5	Bi, *D*, Sq Cm per Sec x 10^5
B-6	2B5	339 ±1	2700	1.059	1.16	2.88	5.62
B-6	2B6	339 ±1	2700	0.887	1.53	3.46	6.02
B-7	2B8	281 ±0.5	1800	0.885	1.53	1.637	3.49
B-7	2B10	281 ±0.5	1800	0.991	1.24	2.31	2.78
B-8	2B14	414 ±0.5	1800	0.870	1.16	11.27	13.55
B10	2B7	300.5±1	3060	0.752	1.53	3.63	4.33
B-11	5B9	390 ±1.5	1800	1.034	1.24	9.15	9.25
B-11	5B10	390 ±1.5	1800	1.079	1.53	8.88	12.7

DIFFUSION coefficients of Ra*D* (Pb^{210}) and Ra*E* (Bi^{210}) in a Bi-0.255 atomic pct Pb alloy have been measured by the methods outlined in a previous paper.[1] The following changes were made in the experimental procedures: the bath was made up of about 400 to 500 g Bi; and no correction was made for the volume change of bismuth on melting.

The data are presented in Table I and Fig. 1. A least-squares analysis of the data yielded

$$D_{Pb} = (0.120 \pm 0.09) \exp(-9680 \pm 1070/RT)$$

$$D_{Bi} = (0.0465 \pm 0.001) \exp(-8100 \pm 466/RT).$$

Statistical analysis of the data indicated that the activation energies are significantly different at the 50 pct level, but not at the 75 pct level, while the D_o values are significantly different at the 97.5 pct level, but not at the 99 pct level. The differences are thus not as clear-cut as they were for lead. However, bismuth diffuses faster than lead in high bismuth alloys as well as in lead.

The high activation energies, more than twice the value calculated from viscosities, are in good agreement with the results of Grace and Derge.[8]

No data were obtained at higher temperatures because of gas bubble formation in the capillary.

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S. J. ROTHMAN, Junior Member AIME, formerly Graduate Student, School of Mineral Sciences, Stanford University, Stanford, Calif., is Assistant Metallurgist, Argonne National Laboratory, Lemont, Ill. L. D. HALL, formerly Assistant Professor, School of Mineral Sciences, Stanford University, is associated with Varian Associates, Palo Alto, Calif.

TN 353E. Manuscript, Dec. 29, 1955.

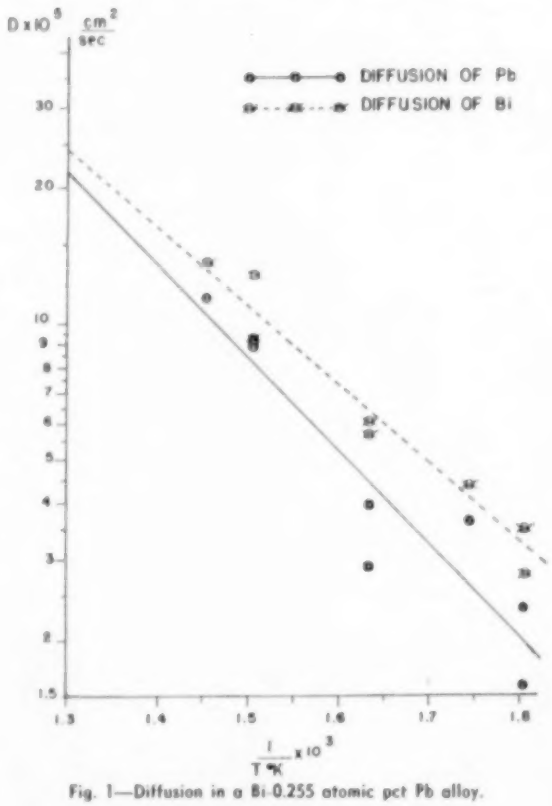

Fig. 1—Diffusion in a Bi-0.255 atomic pct Pb alloy.

References

[1] S. Rothman and L. Hall: *AIME Trans.*, 1956, vol. 206, p. 199; JOURNAL OF METALS, February 1956.
[8] R. Grace and G. Derge: *AIME Trans.*, 1955, vol. 203, p. 839; JOURNAL OF METALS, July 1955.

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AIME NEWS

A Half-Century of Electric Furnace Steelmaking To Be Celebrated at Conference in Chicago

AT the 14th Annual Conference of the Electric Furnace Steel Committee in Chicago, December 5–7, AIME members will be celebrating fifty years of steelmaking. The varied program includes plant trips to Republic Steel Corp. or American Steel Foundries, scheduled for the day preceding the technical sessions.

Headquarters for the meeting will be the Morrison Hotel, and reservations should be made directly with them or other Chicago hotels. The $7.00 registration fee includes a copy of the bound Proceedings when published. Fee for members is $5.00 and students pay no fee unless they desire a copy of the Proceedings. The 1955 Proceedings are available from the Institute. Price is $10.00 to nonmembers ($10.50 foreign) and 30% less to AIME members and past registrants.

Preliminary Program

WEDNESDAY, DECEMBER 5

9 am to 9 pm **Registration**

11 am **Plant Trip**

Leave and return by chartered buses from Morrison Hotel for the South Chicago Works of Republic Steel Corp., or the Indiana Harbor Works of American Steel Foundries. Lunch provided by host companies at Vogel's Restaurant nearby. Return by 4 pm.

THURSDAY, DECEMBER 6

8:30 am **Registration**

9:30 am **Opening Session**

Welcoming remarks; announcements; reports.

9:45 am **Joint General Session**

Appraisal of European electric furnace melting; progress in electric arc furnaces and trends of electric furnace growth; cyclical fluctuations of steel scrap prices.

2:00 pm **Joint Session on Solidification of Electric Furnace Steels**

Discussion of solidification of various metals in ingot and sand molds; macrosegregation, microsegregation, and inclusion types of chrome-nickel and chrome steels; solidification of stainless steel ingots; observations on deoxidation and hot ductility of type 310 stainless steel; shrinkage and density of liquid killed steel in hot topped ingots; relation of ingot structure to transverse ductility of heat treated high strength steel; gas problems in the solidification of steel.

6:30 pm **Reception and Cocktail Party**

7:00 pm **Annual Fellowship Dinner**

Speaker: E. R. Johnson, vice president in charge of operations, Republic Steel Corp., Cleveland.

FRIDAY, DECEMBER 7

8:30 am **Registration**

9:30 am **Ingot Session on Developments for Control of Quality and Interpretation of Results**

Rapid hydrogen analysis and some applications; molded exothermic lined hot tops; statistical machines and methods for quality control.

9:30 am **Castings Session on New Approaches to Hot Tearing Problems and Ladle Refractories**

Relationship of freezing characteristics to hot tearing and deoxidation; evaluation of ladle refractories.

2:00 pm

Ingot Session on Fume Control and Scrap Sources

Smoke and fume control; sources of iron other than scrap; overall picture of sponge iron and H-iron; practical aspects of using sponge iron; molten pig iron; desiliconized pig iron; efficient preheater for electric furnace charges.

2:00 pm

Castings Session on Operations: Bull Session

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Annual Meeting Plans - Metals Branch

IMD, ISD, and EMD Schedule Varied Programs

Iron & Steel Division

Under the leadership of Chairman Michael Tenenbaum, the Iron & Steel Div. is planning to cover a very wide range of subjects at its annual meeting in New Orleans next February 24-28. Sessions will be arranged to present the latest developments where there has been great activity in the iron and steel industry.

A complete session has been arranged jointly by the ISD Mechanical Working Committee and the Institute of Metals Div., covering theoretical aspects of cold rolling as well as recent operating contributions to the manufacture of cold rolled sheets. Recognizing that great strides have been made recently in the field of continuous casting, a complete session has been devoted to this subject. Operating iron and steelmaking sessions will include papers on oxygen-steelmaking, commercial desulfurization, and the sulfur distribution in steelmaking systems.

As usual, the Physical Chemistry of Steelmaking Committee has taken over responsibility for developing its own technical sessions. Of particular interest this year will be a session on the planning and interpretation of pilot plant studies, and one on the reactions of gases in metals.

A session devoted to brief and informal descriptions of research in progress is planned which will not only describe avenues being investigated in our research laboratories, but also indicate the research needs of the iron and steel industry and the manner in which research results can best be utilized to improve existing operations and to plan future processing.

Institute of Metals Division

The Institute of Metals Div. will have several special features as part of its program at the Annual Meeting in New Orleans. A popular part of the IMD schedule, organized by M. E. Nicholson, chairman of the Program Committee, will be the Third Annual Symposium on Semiconductor Metallurgy to be held Monday, February 25. This is sponsored by the Metal Physics Committee under the chairmanship of W. G. Pfann. This one-day symposium will consist of review papers in the morning and research papers in the afternoon. Those wishing to present research papers should send abstracts to W. G. Pfann, Bell Telephone Laboratories, Murray Hill, N. J.

IMD is cooperating with ISD in the presentation of a joint technical session on cold rolling of low-carbon steels. Three papers will be presented, one devoted to the fundamentals of cold rolling, one to the technology of rolling mill lubricants, and the third on problems of aging of cold rolled sheet.

Research seminars and research summaries will provide the opportunity for presentation of recent research papers in the field of physical metallurgy.

Extractive Metallurgy Division

The Extractive Metallurgy Division is planning an active program of seven sessions, and a joint session with the Iron & Steel Div., at which some 40 technical papers will be presented. Of special interest will be the session on copper smelting when papers will be presented on the new plants at San Manuel, at Gaspe, and on the sulfide smelter at Chuquicamata. Sessions will be held on lead and zinc, aluminum, magnesium, and hydrometallurgy. Papers are also scheduled for delivery on titanium, uranium, zirconium, and uncommon metals. At the session on uranium and uncommon metals, a new picture, *The Petrified River—The Story of Uranium*, prepared by Union Carbide & Carbon Corp., is scheduled to be shown.

A session has been arranged on the electrolysis of fused salts, which will include two papers on electrorefining of titanium in a molten chloride electrolyte. The joint session planned by the Physical Chemistry Committee of EMD in cooperation with the Physical Chemistry of Steelmaking Committee of ISD, will present a program on slags and mattes.

A feature of the EMD program is the stag luncheon to be held in the Charcoal Room of the Jung Hotel on Wednesday, February 27, at which time the retiring and incoming division chairmen, and a guest speaker, will address the group. H. W. St Clair, EMD Program Committee chairman, is in charge of all arrangements.

Research in Progress

The Research in Progress session will be quite different at the New Orleans meeting. As arranged by W. J. Harris, Jr., it will consist of a half-hour discussion of government in science, with a speaker from the Naval Research Advisory Committee. Following this will be a 45 min discussion of the basic research program of the government, by a speaker from the Office of Naval Research. Presentations will be by teachers of metallurgical programs from the Atomic Energy Commission, the National Science Foundation, and the NACA. This session on Research in Progress will provide an excellent opportunity for AIME members to learn the overall point of view of the various technical agencies concerning research.

Powder Metallurgy

A half day session will be devoted to invited papers on powder metallurgy, being arranged by the Powder Metallurgy Committee. Included will be a report on metallic filter materials by John Haertlein, Metals Disintegrating Co. A second paper on *Cemented Carbide and Diamond Impregnated Drilling Bits* will be presented by Gerald C. Nalon, Metallurgical engineer, General Electric Co. These papers should be of particular interest to men from industry in the New Orleans area. A panel discussion on high strength structural parts by powder metallurgy will cover *Theory* by Henry H. Hausner, Nuclear Engineering Dept., Penn-Texas Corp.; *Techniques* by George Stern, American Sinteel Corp.; and *Applications* by James M. Copeland, International Business Machines Corp. This program is being arranged by Harold Hirsch and F. V. Lenel.

A luncheon will be held in Hotel Jung following the technical session.

Field Trip

Metals Branch members may be particularly interested in learning of a field trip to the Chalmette Works of Kaiser Aluminum & Chemical Corp., just outside New Orleans, on March 1st. A chartered bus with a maximum capacity of 75 is scheduled to leave the Roosevelt Hotel in downtown New Orleans at 10:00 am for the 280 acre establishment on the banks of the Mississippi River, where 440 million pounds of aluminum are produced annually and 2000 persons are employed. Completed in 1953, the plant incorporates the most modern equipment and techniques and is the largest of its kind in the country. Arrangements for the trip have been made by R. H. Feierabend of Freeport Sulphur Co.

NOHC Southern Ohio Section Holds Annual Meeting in Columbus

The NOHC Southern Ohio Section held its annual meeting on October 5 and 6, at the Deshler-Hilton Hotel in Columbus with a registration of 200. In his welcoming address, Richard W. Lewry, chairman of the section and open hearth superintendent, Detroit Steel Corp., noted the tremendous expansion of the steel industry in Southern Ohio in the last 20 years. His remarks were followed by the presentation of the Section Award Paper to Thomas E. Schwamburger, Detroit Steel Corp.

The technical sessions of the meeting were conducted on two broad topics, *Operating and Combustion*, and *Practice and Quality*, with the former under the joint chairmanship of O. D. Eyre, Armco Steel Corp., and E. L. Allison, Detroit Steel Corp. The four papers which comprised this session were presented by H. V. Flagg and V. W. Jones, Armco Steel Corp., Robert L. Sigl, Detroit Steel Corp., and E. L. Allison.

The gavel at the afternoon session on Practice and Quality was wielded by Kenneth Stambaugh, Newport Steel Corp., and McBeth Sample, Armco Steel Corp. Four papers were delivered by R. G. Phelps, Inland Steel Co., Chester Austin, Kaiser Engineers, and W. H. Mayo and L. G. Ekholm, U. S. Steel Corp.

At the dinner which concluded the technical proceedings of the conference, Don R. Mathews, Alan Wood Steel Co., officiated as toastmaster and introduced the featured speaker of the evening, Ray Hobson, vice president of the Farm Bureau Cooperative Assn.

A meeting of the national executive committee was held on Saturday morning, October 6, after which the section members enjoyed the Stanford vs. Ohio State football contest.

Spectrographers' Assn. Symposium is Scheduled April 1957 in Chicago

The American Association of Spectrographers has made plans for its Eighth Annual Symposium on Spectroscopy, to be held at Chicago's Hotel LaSalle from April 29 through May 1, 1957. An open invitation is being extended to all spectrographers and workers in associated fields to attend the meetings, present papers, and, of course, to enjoy the exhibit of analytical instrumentation which is planned.

Exotic Havana Chosen For Tour Following Annual Meeting

AIME's 1957 Annual Meeting in New Orleans will be followed by a post convention tour to Cuba, including a stay in Havana, and a visit to the Mata Hambre Mine. Departure on a non-stop flight from New Orleans Thursday evening, February 28, begins the tour, which will extend to the following Thursday, March 7.

All those participating will stay at Havana's newest luxury hotel, the Hotel Rosita de Hornedo where accommodations include an air-conditioned bedroom, bath, and private veranda facing the ocean. Two large swimming pools are available.

On Friday afternoon, a sightseeing trip through Havana in private cars is featured, and Saturday's program includes a drive through the surrounding countryside and a visit to one of the perfume factories. Luncheon will be at the Rancho Luna, whose open, palm leaf covered dining room is surrounded by large gardens of sugar cane, coffee, and a variety of vegetables. Guests will be entertained with Cuban music and dances, followed by a cockfight exhibition and a Royal Palm climbing contest.

A scenic motor trip to the lovely Valley of Vinares will start from Havana on Sunday morning, with luncheon at Spa San Vincente. The afternoon will be devoted to pleasure excursions through the incomparable flower gardens of the Valley.

On Monday, a trip to the Mata Hambre Mine is scheduled which features a guided inspection tour and a luncheon given by the management. Tuesday afternoon, participants will begin their trip back to Havana over a different highway.

Wednesday, March 6, the last day of the tour, has been left open for individual sightseeing and shopping. The tour will be terminated on Thursday with the flight back to New Orleans.

ECPD Annual Program Held in Detroit

The 24th Annual Meeting of the Engineer's Council for Professional Development was held on Thursday and Friday, October 25-26, at the Engineering Society of Detroit.

A varied program of technical and social events was arranged under the leadership of ECPD president, Thorndike Saville, who also addressed the group on Thursday morning. His speech was followed by talks on *The First Five Years of Professional Development*, by John J. Cronin, C. J. Freund, and A. C. Monteith. The luncheon speaker was Kenneth McFarland.

In the afternoon, simultaneous panel discussions were held on the above topic; Max W. Johnson led the investigation of orientation, training and appraisal, while K. A. Meade was in charge of the panel on continued education and selected reading, and H. P. Seelye directed the discussion on professional identification and integration into the community. At the Annual Dinner that evening in the Statler Hotel, guests heard an address by J. H. Foote.

Friday morning featured open meetings of the following committees: Guidance, Student Development, Ethics, Training, and Recognition. The Ethics Committee tackled interesting if thorny problems. L. F. Grant led the examination of salaries: *Is it ethical for an employer to pay salaries to experienced engineers which are too low compared to wages offered recent engineering graduates?* J. J. Uicker presided over the discussion on change of employment: *In a new job may an engineer use information considered confidential, which he has developed for his former employer?* This topic was followed by the question: *Should a research engineer withhold his results, valuable to the profession, at the insistence of his employer?* Lastly the group, led by J. H. Foote, discussed the ethics of a senior student who has promised to accept a position after graduation, considering another offer.

At the open council meeting in the afternoon reports of the standing and special committees were read.

The ladies too, were kept busy with coffee hours, a visit to the Detroit Art Center, a tour and luncheon at General Motors Technical Center, and a visit to Cranbrook and Northland.

Publications Chairmen

The AIME Technical Publications Committee has announced the new chairmen of the Divisional Publications Committees. They are as follows: Gerhard Derge, Iron & Steel Div.; H. H. Kellogg, Extractive Metallurgy Div.; and C. E. Birchenall, Institute of Metals Div.

Metal Treating Institute Presents Annual Award

One of the highlights of the Metal Treating Institute's 40th Annual Meeting in Cleveland October 7, was the presentation of the MTI Achievement Award made to the author of the most outstanding lecture or feature article during the preceding year. Winners A. E. Gurley and C. R. Hannewald, joint authors of *Development and Application of the Iso-Hardness Diagram*, received the award from Howard N. Bosworth, Bosworth Steel Treating Co., Detroit, on Saturday, October 6th, the second day of the three-day conclave.

The Friday sessions featured the report by the chairman of the labor relations committee, C. M. Cook, supported by a film on supplemental unemployment benefits. Two illustrated lectures on technical subjects were presented in the afternoon. H. L. Hovis discussed *Vacuum Annealing and Bright Hardening*, which was followed by a talk on *Four Steps to Better Tools and Dies* delivered by Joseph S. Pendleton, Jr.

During the Saturday morning gathering, A. O. Schaefer, president of ASM, delivered an address on *America Needs Metallurgists*. This was followed by a symposium on *Metal Treating* Magazine. In the evening, dancing and a floor show enlivened the annual reception and banquet. The meeting ended on Sunday morning with a business session devoted to the election of officers and board members.

Mudd Memorial Fund Sponsors Publications On Minerals and Rocks

The AIME Board has appropriated $20,000 from the Seeley W. Mudd Memorial Fund for a third completely revised edition of *Industrial Minerals and Rocks*. The first edition was published in 1937 and the second in 1939. The volume, now out of print, has been one of the most popular ever published by the Institute.

The Mudd Fund is also underwriting publication of a volume on mineral economics which it hopes to have available next year. Practically all authors of the various chapters have accepted the assignment, outlines of most of the chapters have been received, and the preliminary text of a few. Evan Just is chairman of the editorial committee for the volume and Edward H. Robie, editor. This volume will be in memory of Harvey S. Mudd and has been made possible by an additional gift to the Seeley Mudd Fund by Mr. Harvey Mudd's widow, son and daughter.

Scholarships Offered For Graduate Science Study

The National Science Foundation has announced its plan to award approximately 800 graduate and 120 postdoctoral fellowships to individuals undertaking graduate study in the sciences during the 1957-1958 academic year. Grants will be made only to U. S. citizens, and solely on the basis of ability, with the proclamation of winners scheduled for Mar. 15, 1957.

These fellowships will be awarded in the mathematical, physical, medical, biological and engineering sciences. Certain inter-disciplinary fields (e.g., geophysics) are included and fields of convergence where the study of a natural science is interrelated with some aspect of the social sciences.

Applications for graduate fellowships must be submitted by Jan. 7, 1957, to the Fellowship Office of the National Academy of Sciences-National Research Council, 2101 Constitution Ave., N. W., Washington 25, D. C. Those for post-doctoral grants will not be accepted after Dec. 24, 1956.

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Third Annual Rocky Mountain Minerals Conference Scores With Sessions, Social Events and Guests

The Third Rocky Mountain Minerals Conference held again at the Newhouse Hotel in Salt Lake City, September 26-28, was an unqualified success. Sponsored by the AIME Utah Section, the Conference drew 650 registrants and a score of outstanding leaders in the minerals industry. Two and one-half days of technical sessions were followed by half-day field trips embracing operations in the Salt Lake Region.

Officers of the conference and of the Utah section get together. Left to right: R. C. Cole, General Conference Chairman; A. J. Thuli, Assistant General Conference Chairman; D. F. McElhattan, section Vice Chairman; Neil Plummer, section Chairman; and Glen A. Burt, section Secretary-Treasurer.

Social Events

Among the highlights was a speech by Governor J. Bracken Lee of Utah, who addressed the welcoming luncheon on Wednesday, September 26. His frank and informal views on trends in national and local government proved stimulating. That evening, registrants had a second opportunity to become better acquainted at the parties sponsored by the mining companies and suppliers. Other social events included the minerals luncheon on Thursday at which John C. Kinnear, Jr., EMD chairman, spoke on the importance of human dignity. He cited examples from his wide range of experience, emphasizing the significance of this point in dealing with superiors and subordinates. Winding up the conference were two social functions enjoyed by all: the cocktail party and informal dinner-dance on Friday evening.

Technical Sessions

The wide range of papers presented morning and afternoon on Wednesday and Thursday, ranged from the problems encountered at the Calera cobalt refinery to the prospects for phosphate mining in Israel. The sessions were well organized and avoided the problem of simultaneous scheduling. The sixteen papers presented covered extractive metallurgy, coal mining, oil and gas resources, management problems, mining methods, and other topics. One of the featured speakers on Thursday was Marling J. Ankeny, recently appointed director of the U. S. Bureau of Mines, who detailed what the agency has done for the metal mines in the 11 Western states.

The Minerals Luncheon on Thursday had John C. Kinnear, Jr., as guest speaker. R. C. Cole, General Conference Chairman, is shown speaking.

On Friday morning registrants were off to a fast start at the miner's breakfast which featured a fancy menu to be enjoyed unshaven and in western attire. This was followed by an all-morning symposium, *Loading and Transportation*. Under the guidance of J. M. Ehrhorn, seven authors read papers on open pit and underground operations. A comprehensive picture of the newest methods, practices, and equipment was presented by specialists in the various phases of loading and moving ore. This session was well attended and marked by interesting discussion.

Field Trips

Four field trips left promptly at 1:30 Friday afternoon and visitors had a choice of touring the Calera cobalt production plant, the refinery of the Utah Oil Refining Co., the Western Phosphates plant, or the Vitro Uranium mill. The good turnout was rewarded with hosts who made certain that their guests were well informed and had ample opportunity to view the details of the operation.

For The Ladies

The distaff made merry at a coffee party at the Newhouse Hotel, Wed-

nesday morning, and at the luncheon and fashion show on Thursday at the Salt Lake Country Club, in addition to their active participation at the dinner-dance on Friday. Women's auxiliary events at the conference were under the direction of Mrs. F. V. Richard, chairman, assisted by Mrs. Paul Shields, chairman of the WAAIME Utah Section.

Credit Due

Particular credit should go to the many people who contributed to the smooth running organization of the meeting. Notable work was done by the following chairmen: R. C. Cole, general chairman; A. J. Thuli, assistant general chairman; A. G. Kirkland, program; I. K. Hearn, arrangements; P. H. Ensign, entertainment; and J. A. Burke, registration. The officers of the Utah Section which sponsored the conference, were much in evidence: Neil Plummer, chairman; D. F. McElhattan, vice chairman; and Glen A. Burt, secretary-treasurer.

ABOVE: Miner's Breakfast on Friday carried this invitation, "come unshaven, in western garb."

LEFT: Chairman and speakers at the Symposium on Loading and Transportation included: A. G. Kirkland, Program Chairman; A. J. Thuli, Session Host; J. M. Ehrhorn, Moderator; and the speakers, L. W. Casteel, R. F. Love, R. I. Williams, W. H. Wamsley, A. R. Sims, D. I. Hayes, and Tom Berry (not shown).

FIELD TRIPS: Cobalt refinery of Calera Mining Co. on the shore of Salt Lake was one of the plants visited on Friday afternoon. Left: visitors stream off bus. Center, J. S. Mitchell, plant manager of Calera Mining Co. provides description. Right, refinery building.

AROUND THE SECTIONS

• The **Boston Section** of AIME held its first meeting of the year on October 1st, with dinner at the MIT Faculty Club and a technical discussion in Sloan Building. Metallurgy of transistors was the topic for the evening, and B. H. Alexander the guest speaker. A graduate of Montana Schools of Mines and Carnegie Institute of Technology, Dr. Alexander is manager of semiconductor operations at C. B. S.-Hytron in Lowell, Mass.

• **St. Louis Section** members accepted the invitation of A. P. Green Fire Brick Co. to visit their plant in Mexico, Missouri on Friday, October 12. The group met in the morning for tours of the clay pits and then enjoyed a barbeque luncheon provided at the company's clubhouse. After lunch, a trip was taken through the plant, where a complete line of fire-clay refractories and refractory and insulating castables is manufactured. The company's output of six million bricks per month makes it the largest single fire brick producer in the world.

• An attendance of over 80 members and their wives attested to the success of the **Adirondack Section's** September 22nd meeting in Fairlee, Vt. The presence of AIME President Carl E. Reistle, Jr., and a field trip to Appalachian Sulfides were the features which attracted this impressive gathering.

Local Section Changes

Petroleum Branch members in Duchesne and Uintah Counties, Utah, are now included in the area of the **Denver Petroleum Section** whose new Uintah Basin Subsection now includes, besides the two counties named, the following counties in Colorado: Garfield, Mesa, Moffat, Rio Blanco, and Routt.

A part of the territory of the **Kansas Section** has been assigned to a new Local Section to be known as the **Great Bend Local Section.** It comprises the following Kansas counties: Ellsworth, Rice, Barton, Stafford, Pratt, Kiowa, Edwards, Hodgeman, Pawnee, Ness, Rush, Trego, Ellis, Russell, Rooks, Graham, Grove, Sheridan, Norton, Phillips, Cheyenne, Rawlins, Decatur, Sherman, Thomas, Wallace, Logan, and Lane.

In Venezuela, the **Venezuela Petroleum Section** has released some of its territory to the new **Western Venezuela Petroleum Section.** Its area includes the following states: Zulia, Tachira, Merida, Trujillo, Lara, Falcon, Yaracuy, Portuguesa, Cojedos, Barinas, and Apure

• The **San Francisco Section** met on September 12, at The Engineers Club for their monthly dinner and technical session. Featured speaker for the occasion was Chester Austin, manager of the development section, Steel Plants Div., Kaiser Engineers. Mr. Austin discussed the manufacture of oxygen converter steel, illustrating his talk with a movie on the oxygen converter in operation.

The next meeting of the Section was on Wednesday evening, October 10th at The Engineer's Club, to hear an address by Ian Campbell, Division of Geological Sciences, California Institute of Technology. After cocktails and dinner, the members gave their attention to Dr. Campbell's talk on Petrology and the Industrial Minerals and then watched a 23 min color film entitled *Portrait of the Earth.* In addition to describing the latest developments in airborne photographic and geophysical methods, this film, loaned to the section by Hycon Aerial Surveys, graced the evening with some lovely color shots of California, the Colorado Plateau, and the Peruvian Andes.

• The **Montana Section** AIME opened the 1956-57 season of activities with its second annual Columbia Falls Dinner Meeting and Plant Inspection trip on Saturday and Sunday, September 22-23. Program chairman R. G. Bowman and committeemen H. G. Satterthwaite and George Hanson arranged a dinner meeting at Club Rocco, Hungry Horse, Mont. at which Kent I. Newman spoke on *Mechanization in Aluminum Production,* and Hal W. Kanzler delivered a paper on *The Electrical Installation at Columbia Falls.*

On Sunday, September 23rd, members and their distaff companions took a guided inspection trip through the Columbia Falls plant of Anaconda Aluminum Co. During the business meeting, Clarence V. Saylor was elected chairman of the section to complete the unexpired term of Robert Van Pelt, who resigned the presidency of Montana School of Mines to assume the same position at Michigan College of Mining and Technology.

• The **New York Section** met at the Mining Club on September 20, to take an annual forward look at base metal prospects. Simon D. Strauss, vice president and sales manager, American Smelting & Refining Co., spoke on the prospects for nonferrous metals, and Irving Lipkowitz, assistant to the president, Reynolds Metals Co., did the crystal gazing for aluminum.

• The **Reno Sub-Section** held their regular luncheon meeting on September 14, in the Nevada Room of the Mapes Hotel. Guest speaker was Governor Charles H. Russell of Nevada, who was introduced by E. L. Stephenson, Section Chairman.

• The **Colorado Section** held a dinner meeting on September 19, at the University Club in Golden, with Frank F. Argust, Colorado Fuel & Iron Corp., speaking on *Materials Handling.*

The Science of Making Brass, **a half-hour, award-winning color film has been made available on free loan to technical groups. It is sponsored by Chase Brass & Copper Co., and explains the step by step process of making brass and other copper alloys by showing a tour through the Chase Mills in Waterbury, Conn. Awarded first prize in an international competition for technical films at Turin, Italy, the film also received an award at the Venice Festival. It may be obtained from** *Modern Talking Picture Service, Inc., 3 East 54th St., N. Y. 22.* **The distributors advise organizations desirous of showing the film to arrange for its use at least one month prior to the planned playdate.**

A scene from the prize-winning film, *The Science of Making Brass.*

Quality Unlimited, **a new 30 min sound-color film on the manufacture of wire rope, has been made available by the Wickwire Spencer Steel Div., of The Colorado Fuel & Iron Corp. The film follows all the operations of wire rope production from basic steel making to finished rope testing, with special emphasis on the physical and chemical tests of quality and on the applications and care of wire rope. For information on obtaining copies, write to** *The Colorado Fuel & Iron Corp., 575 Madison Ave., New York 22, N. Y.*

More than 20 films made by Allegheny Ludlum Steel Corp. are available for showing at regional meetings. Most of the movies are in color

and all prints are 16 mm with sound. There are general films as well as technical movies on such subjects as the making of stainless steel. A revised list of the films has been published and may be obtained by writing to the company's *Advertising Dept., 2020 Oliver Bldg., Pittsburgh 22, Pa.*

• The **Utah Section** of AIME has pioneered a new idea in its membership development program which has proved outstandingly successful. The plan provides that each member of the section who secures five Utah residents as new members in any one calendar year will receive prepaid dues for the following year.

The plan is completely administered by the local section. It is self-financing, with the section paying dues of those who secure five new members, out of its refund from the AIME New York office of 50 pct of all initiation fees. Since normally 60 pct of the new members join as a Member or Associate Member, the section receives an average of $30 rebate from the initiation fees of five new members.

If you are interested in strengthening your local section, discuss this idea with your officers, and arrange to notify the section membership by letter should you adopt the plan.

The Utah Section's letter to its membership stated:

"The Utah Section of the AIME would like to pay your dues.

"A plan has been evolved whereby any member of the Utah Section who obtains five new Utah Section members in any one calendar year will receive in return prepaid dues for the following year. For 1956 this program will be effective as of April 1, with the termination of the 1956 drive on Dec. 31. Thenceforth each succeeding yearly drive will cover the 12-month calendar period. A large percentage of our present membership should be able to benefit by this offer as there is a very large group of potential AIME members in this area.

"Enclosed are five AIME application forms which upon completion should be returned for further handling. Please be sure to indicate on each application, who is to receive credit for obtaining the new member, as this will be the basis for determining which members qualify for payment of dues.

"There is only one way that a membership committee can do a really outstanding job and that is through the active and enthusiastic participation of the membership as a whole. We have a good product to sell, the Utah Section. Will you help us sell it?"

C. H. Henline
Membership Chairman

Why not start your section's drive next month?

BOOKS

ORDER YOUR BOOKS THROUGH AIME—Address Irene K. Sharp, Book Dept. AIME members given 10 pct discount whenever possible. Please order Government publications direct from the agency concerned.

Lehrbuch der Bergbaukunde, Volume I, by C. Hellmut Fritzsche, *Springer-Verlag,* Berlin, available in the U. S. from Stechert-Hafner, 31 E. 10th St., New York 3, N. Y., approximately $8.50, 759 pp., 9th ed., 1955.—This first volume of a series in German on mining and mining methods provides a comprehensive and extensive treatment of drilling, recovery, methods, haulage, ventilation, dust problems, and lighting. Although the emphasis is on coal mining, other types of underground mining—ore, salt, petroleum—have also been considered. Fully illustrated, the book is encyclopedic in character.

Movements of the British Iron and Steel Industry—1720 to 1951, by Howard G. Roepke, *University of Illinois Press,* Urbana, Ill., $4.00, cloth; $3.00 paper, 1956.—This study by a professor at the University of Illinois, was made while the author was in England on a Fulbright Fellowship. Prof. Roepke found that technical inefficiency due to resistance to change which handicapped the British iron and steel industry during World War II, is still hampering its expansion. In America the industry has tended to follow the British example, but could profit from observing their mistakes. The early history of the British industry was marked by a determination to lead the world in using the best techniques at the most favorable locations. More recently, the predominant tendency has been to patch old iron works in existing locations rather than to build new plants at the ore fields.

Please Order These Publications from the Publishers

Creep and Fracture of Metals at High Temperatures, *Her Majesty's Stationery Office,* 423 Oxford St., London W. C. 2, $4.20, 412 pp., 1956.—This book presents the proceedings of a symposium held at the National Physical Laboratory in 1954. The 22 papers are divided into four sections: deformation processes in simple materials; creep resistance of complex materials; theory of fracture; and work on tertiary creep and fracture.

Metal Statistics 1956, edited by N. J. Langer, *American Metal Market,* 18 Cliff Street, N. Y. C., $3.50, 844 pp., 1956.—This 49th annual edition contains a general assortment of statistical information on ferrous and nonferrous metals. Included are new statistical tables such as titanium ingot and mill product shipments; world production of nickel; refiner's buying prices for copper scrap; consumption of solder in the U. S.; use of tin and lead in solder; manganese ore consumption; electrical conductivity of metals; etc. Statistics dealing with production, consumption, imports, and exports are gathered from such authentic sources as the AISI, USBM, and Census Bureau.

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(Continued from page 1498)

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Metallurgists

Several openings exist in the Metallurgical Departments of our plants in Cleveland, Pittsburgh and Aliquippa, Pa. for metallurgists with the B.S. degree and up to five years experience, preferably in the steel industry.

Opportunity for varied experience, leading to increasing responsibility and earning capacity in metallurgical investigation, customer contact, or operations supervision.

Of particular interest would be experience in production of electric-weld line pipe (Aliquippa) and arc furnace melting (Cleveland).

Openings also for research metallurgists (Ph.D., M.S., or B.S.) at our Pittsburgh laboratories.

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Components Beach-Russ, 100 CFM Mechanical pump operated by 5 HP, 440 V, 60 Cycle, 3 P. Motor, Booster Oil Pump, 5000 W Calrod Heater. Oil diffusion Pump, Mechanical Refrigeration unit. 2 Westinghouse McLeod Gauges. 12" Valve at outlet of diffusion pump. Units have been tested as low as 50 Milli-Microns. Condition used, good. Quality 7. Price $2,750.00 each.

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PERSONALS

Avery C. Adams, president of Pittsburgh Steel Co. since 1950, has been elected president of Jones & Laughlin Steel Corp. A graduate of Yale University, he has also held executive positions with Inland Steel Corp., Portsmouth Steel Co., and Detroit Steel Co.

August J. Durelli has been appointed professor of civil engineering at Illinois Institute of Technology. A native of Argentina, Dr. Durelli attended the University of Buenos Aires. He is the author of four books and many papers on his specialty, stress analysis.

Samuel Storchheim has been promoted to chief of manufacturing engineering and research in the Nuclear Div., Glenn L. Martin Co., Baltimore. Prior to joining Martin in 1955, he had been metallurgical engineer, Atomic Energy Div., Sylvania Electric Products Corp., Bayside, N. Y.

Edwin A. Gee, formerly manager of the plants technical section, manufacturing division, E. I. du Pont de Nemours & Co., Wilmington, Del., has been named sales manager of pigment colors. Dr. Gee was assistant chief metallurgist for the USBM before joining du Pont in 1948.

R. A. AEBERLY

R. A. Aeberly has been named Los Angeles district manager, Electro Metallurgical Co., to replace **S. L. Jackson,** who has been transferred to New York.

Ralph C. Hanson, former refractories engineer and assistant vice president, E. J. Lavino & Co., Philadelphia, has joined the Ramtite Co. as special representative co-ordinating sales in the Pittsburgh office.

John P. Holt has been appointed executive assistant to the vice president in charge of sales at Basic Incorporated, Cleveland. He had been manager of the company's St. Louis office since 1953.

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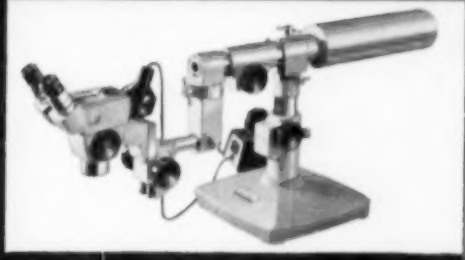

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R. M. Burns has been awarded the Acheson Medal of the Electrochemical Society for 1956. The award, which carries a cash prize of $1000, recognizes the contribution of Dr. Burns' work on the corrosion of metals, to the objectives, purposes, and activities of the society. Dr. Burns is associated with Stanford Research Institute, and is scientific adviser to the Sprague Electric Co.

J. A. Yoblin is carbide products development engineer, Metallurgical Products Dept., General Electric Co., Detroit.

Abraham Dor has returned from Tel Aviv, where he was chief engineer for Israel Mining Industries, to accept an assignment as project engineer, Bechtel Corp., San Francisco.

E. J. ANDBERG

E. J. Andberg, formerly of Globe Iron Co., Jackson, Ohio, is now in the Blast Furnace Div., Great Lakes Steel Corp., Detroit.

Robert B. Heppenstall, Jr., has been appointed general manager, Ring Div., Heppenstall Co., Indianapolis.

Roy C. Martin has joined the Cannon-Muskegon Corp., Muskegon, Mich., as metallurgist. He was formerly associated with Metals Research Laboratory, Union Carbide & Carbon Corp., Niagara Falls, N. Y.

Gentaro Matsumura, who has been associated with the Government Industrial Research Institute, Nagoya, Japan, will be studying at the University of Notre Dame's department of metallurgy in Notre Dame, Ind.

R. W. Herzer is now with the Aluminum Co. of Canada, Montreal, having recently returned from Minas Gerais, Brazil, where he was associated with Eletro-Quimica Brasileira S. A., part of Aluminium Ltd.

James O. Steigler has joined the staff of Oak Ridge National Laboratory, Union Carbide Nuclear Co., a division of Union Carbide & Carbon Corp. He was formerly associated with Purdue University.

J. H. CALLENDER

John Hancock Callender has been awarded the first annual Allmetal Stainless Steel Award for an article entitled *The Design of Stainless Steel Curtain Walls.* The award is sponsored by Allmetal Screw Products Co., Garden City, N. Y., and brings to its recipient a $1000 cash stipend. Mr. Callender, an architectural consultant, is currently engaged in work at Southwest Research Institute on permanent arctic buildings for the U. S. Air Force.

Carl F. Hayden, president and treasurer of Hayden & Co., Chicago, has been named Chicago district representative of The Rust Engineering Co.

D. TIMMERMAN

Dietrich Timmerman has been appointed chief engineer of the Rolling Mill Dept., Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.

Thomas F. Kaveney, formerly with Allegheny Ludlum Steel Corp., is now metallurgist with Northeastern Steel Corp., New Haven, Conn.

Henry Allen, Jr., has been promoted to assistant superintendent, International Smelting & Refining Co., Miami, Ariz.

J. P. Dempsey, formerly project engineer with Central Farmers Fertilizer Co., is now chief metallurgist, Tripp Research Corp., Dallas.

Ernest W. S. Ward has resigned as assistant mill superintendent, Gunnar Mines Ltd., to become primary treatment plant superintendent, Deloro Smelting & Refining Co. Ltd., Deloro, Ontario, Canada.

Charles M. Parker has been re-elected assistant vice president, American Iron & Steel Inst., New York.

Edmund C. Burke, formerly of Dow Chemical Co., Midland, Mich., is now on the staff of Hunter Engineering Co., Riverside, Calif.

E. C. BURKE

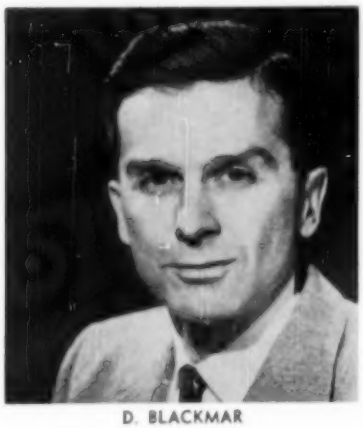
John N. Andersen, formerly of Kennecott Titanium Dev. Corp., Columbus, Ohio, has joined the staff of Kaiser Aluminum & Chemical Co., Oakland, Calif.

J. Donald Judge has been named director of research and engineering at The Hamilton Foundry & Machine Co., Hamilton, Ohio.

H. T. SUMSION

H. Theodore Sumsion has transferred from General Electric Co.'s Knolls Atomic Power Lab. in Schenectady to the Atomic Power Equipment Dept., San José, Calif.

Don Blackmar has been named chief metallurgist in charge of the LeRoi metallurgical and chemical laboratory, Westinghouse Air Brake Co., Milwaukee.



D. BLACKMAR

Herbert R. Hanley has returned to the Missouri School of Mines, Rolla, Mo., where he is Professor Emeritus, to resume limited duties. Since 1954 Dr. Hanley has been academic advisor to Free China's Provincial College of Engineering. He was sent by the U. S. International Cooperation Administration to join the Purdue University team in Taipei, Formosa, under the ICA educational program. In addition to planning and supervising the establishment of a new department of mining and metallurgy, Dr. Hanley lectured, directed laboratory work, conducted student visits to local factories and mines, and personally donated 169 volumes to the departmental library. He has been associated with the Missouri School of Mines since 1923.

Richard E. Cole has been transferred from the Longview, Wash., plant of Reynolds Metals Co. to Sheffield, Ala., where he will be superintendent of production in the new reduction plant now under construction.

Victor J. Obrig, formerly chief metallurgist, Fabricast Div., General Motors Corp., is now foundry manager of the Sterling Foundry Co., Wellington, Ohio.

Donald E. Cadwell has joined the staff of Minnesota Mining & Manufacturing Co., St. Paul. Previously he was employed as a metallurgist, by Dow Chemical Co., Pittsburg, Calif.

O. W. Reen has been transferred from Allegheny Ludlum Steel Corp.'s Carmet Div., Mich., to its research laboratory in Brackenridge, Pa.

Joseph C. Danko is senior research engineer, Westinghouse CAPA, Pittsburgh.

Robert L. Bird is research metallurgist, The Bunker Hill Co., Kellogg, Idaho.

Cr, Hf, Ir, Mo, Nb, Os, Pd, Pt, Re, Ta, Ti, V, W, Zr

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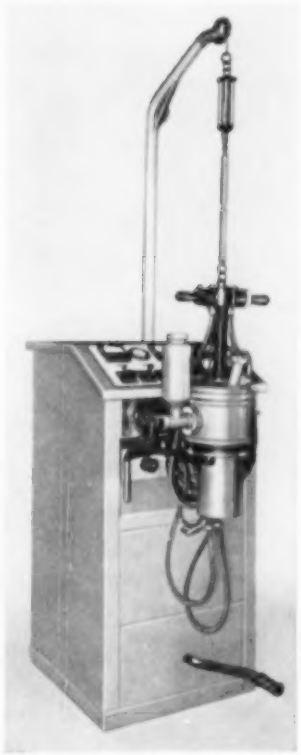
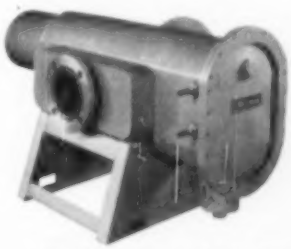


The Heraeus Vacuum Arc Melting Furnace Model VA-L200B, smallest of a line of Heraeus Furnaces sold by CEC.



This Roots pump maintains low, vapor-free pressures. A motor operating within the vacuum drives its rotary frictionless pistons.

With this new Heraeus Arc Melting Vacuum Furnace, the VA-L200B, you can get vacuum melts in "buttons" or ingots.

You can get them of Titanium, Zirconium, Tungsten, and other metals or alloys with high melting temperatures. You can get them fast and pure.

Super-fast mechanical pump—A Roots mechanical vacuum pump pulls pressures in the furnace down to 5×10^{-2}mm Hg—*fast.*

Its throughput of 10,400 micron CFM at 10 microns easily handles sudden gas bursts encountered with certain metals.

No oil contamination—The Roots pump's frictionless rotary pistons require no oil sealing. There can be no contamination from backstreaming vapors in the system.

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Fixed or consumable electrodes—You may use either fixed electrodes of tungsten or metallic carbides, or consumable electrodes of the metal you are melting.

This Heraeus furnace has many other features valuable in laboratory or small-scale production, including exceptional economy—operating either under vacuum or with an inert gas atmosphere.

Heraeus of Hanau, Germany, has licensed CEC as exclusive agent for Heraeus Arc Furnaces (and Roots Pumps) in this country. Complete details in our Bulletins P8-20 and P4-28.

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J. W. HANLEY

John W. Hanley has been promoted to chief metallurgical engineer, Cerro de Pasco Corp., with offices in N. Y. A staff member since 1933, Mr. Hanley will have control over all the metallurgical functions and activities of the corporation.

Victor Little is plant superintendent, Canadian Copper Refiners Ltd., Montreal.

Alfred E. Beck, Jr., formerly of U. S. Metals Refining Co., is now with American Metal Co. Ltd., New York.

F. W. HANSON

F. W. Hanson has been appointed Houston district sales engineer for Electro Metallurgical Co. Associated with Electromet since 1939, Mr. Hanson has also held engineering and production jobs with Hunt Spiller Mfg. Co. and Carnegie-Illinois Steel Co.

Alvin F. Kroll is managing plant operations at the sales and fabrication division, The Bunker Hill Co., Seattle, Wash.

Matthew J. Galvez heads the fuel elements group, Nuclear Div., Glenn L. Martin Co., Baltimore.

Winslow W. Bennett is with Foote Mineral Co., Philadelphia. He was formerly associated with Electro Manganese Corp., East Orange, N. J.

Joseph A. Pask, professor of ceramic engineering, University of California, has been named vice chairman of the school's Mineral Technology Div., which includes mineral exploration, mining, physical metallurgy, extractive metallurgy, ceramics, and petroleum engineering.

William Hegmann, Jr., has been assigned to the Arkansas and Oklahoma territories as sales representative for the Walsh Refractories Corp., St. Louis.

C. S. Barker is chief metallurgist, Norma-Hoffmann Bearings Corp., Stamford, Conn.

D. B. REEDER

David B. Reeder has been appointed western manager of metallurgical service for Electro Metallurgical Co., a Union Carbide & Carbon Corp. Div. He will be succeeded as manager of the San Francisco region by **H. J. Pfeifer,** former manager of the Houston district.

H. J. PFEIFER

Thomas J. Hughel has left the faculty of Purdue University in Lafayette, Ind., to become senior research engineer on the staff of General Motors Corp. in Detroit.

Benjamin N. Webber, formerly with the U. S. Geological Survey, is now in the Foreign Exploration Div., M. A. Hanna Co., in Sinaloa, Mexico.

N. A. GOKCEN

Nev Altan Gokcen is associate professor of metallurgy at the University of Pennsylvania, a position he had previously held at Michigan College of Mining and Technology, Houghton, Mich.

D. J. MARTIN

Daniel J. Martin, vice president, Hughes Tool Co., Houston, has been named to the board of directors of Trans World Airlines. A graduate of the Naval Academy and Stanford University, he received his doctorate from Harvard University, where he was a Gordon McKay scholar.

Charles L. T. Edwards and **Albert P. Spooner** have received Lehigh University alumni awards for having "distinguished themselves both by personal achievement and service as to bring lasting recognition and credit to themselves and to Lehigh University."

Vikash C. Kashyap is at Kashmir Metal Mart, Srinigar C. Kashmir, India. He had been at Purdue University in the department of chemical and metallurgical engineering.

Herbert H. Kellogg has been promoted from associate to full professor of mineral engineering at the School of Mines, Columbia University, New York.

OBITUARIES

Charles R. Austin (Member 1942) died in New Rochelle, N. Y. on May 31, at the age of 58, after a brief illness. A native of Manchester, Eng., Dr. Austin was a Fellow of the Royal Institute of Chemistry in Great Britain. In this country he was in charge of metallurgical research for National Tube Co., Pittsburgh, later a section engineer for Westinghouse Electric Corp. which he left in 1934 to join the staff of Pennsylvania State College. In 1945 he became research director for the Meehanite Metal Corp., the position he held at the time of his death. Dr. Austin was chairman of the education committee, ASM, and received the society's Henry Marion Howe Gold Medal for the best paper in 1946. His published works include more than 50 technical papers on metallurgy, engineering and allied subjects.

G. Richard Gerhard (Member 1932), an alumnus of the universities of Kentucky and Michigan, has died. Born in Augusta, Ky., in 1910, he began his professional career as an analyst in the metallurgical department of the American Rolling Mill Co. In 1935, he joined the staff of the Metal Processing Dept., University of Michigan, as a technical assistant, becoming a full time instructor in 1939. Mr. Gerhard, whose principal interest was in iron and steel metallurgy, became associate professor in the College of Engineering, University of Kentucky, in 1947.

Albert J. Hoch (Member 1954) died on February 27, 1955, at the age of 55. He had been employed as a metallurgical engineer by the Wheeling Steel Co., Steubenville, Ohio.

William J. Linney (Member 1935) died of a heart attack at the age of 44 on August 23 at Port Henry, N. Y. A native of Old Forge, Pa., Mr. Linney was a graduate of Worcester Academy and studied at the University of Vermont. He began an eight-year association with Chateaugay Ore & Iron Co. in 1932, working up from assistant mining engineer to superintendent of the mill and sintering plant. In 1940, he joined Republic Steel Corp. as general superintendent of the Chateaugay Div., Adirondack District, and in 1952 was named district manager of Chateaugay and Port Henry.

NECROLOGY

Date Elected	Name	Date of Death
1942	Charles R. Austin	May 31, 1956
1942	Rex E. Cheek	Unknown
1921	Joe Crites (Senior Member)	Aug. 13, 1956
1947	Adrian Esteve	Oct. 3, 1956
1932	G. R. Gerhard	Unknown
1954	Albert J. Hoch	Feb. 27, 1955
1951	Stephen J. Latanision	July 12, 1956
1935	William J. Linney	Sept. 23, 1956
1943	Walter B. Longan	Unknown
1949	Joseph J. Maucini	Dec. 1955
1924	George C. Newton	May 25, 1956
1883	Leonard Peckitt (Legion of Honor)	Unknown
1946	Lyttleton Price	Unknown
1955	Robert C. Pruess	August 1956
1936	Hidenosuke Sano	Unknown
1946	H. Kirk Stephenson	Sept. 1956
1939	William B. Wells	Mar. 15, 1954
1936	A. S. Wilson	Feb. 26, 1956

MEMBERSHIP

Proposed for Membership
Metals Branch, AIME

Total AIME membership on Sept. 30, 1956 was 25,668; in addition 2,848 Student Associates were enrolled.

ADMISSIONS COMMITTEE

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The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

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Larry Kaufman, Malden, Mass.
Eugene H. Sieckman, Great Falls, Mont.

COMING EVENTS

Nov. 13, AIME, NOHC Buffalo Local Section, annual meeting.

Nov. 13-15, Investment Casting Inst., annual meeting, Sheraton Cadillac Hotel, Detroit.

Nov. 14, AIME, NOHC Western Local Section, Rodger Young Auditorium, Los Angeles.

Nov. 27-30, National Chemical Exposition, trade show, technical programs, and special features; co-sponsored by Amer. Chemical Soc. Cleveland and Chicago Local Sections, Cleveland Public Auditorium, Cleveland.

Nov. 27, AIME, Connecticut Local Section. Speaker: W. A. Backofen, MIT; subject: *Mechanical Metallurgy.* Bridgeport, Conn.

Dec. 4, Soc. for Applied Spectroscopy, Hotel New Yorker, New York.

Dec. 5-7, AIME, Electric Furnace Steel Conference, Hotel Morrison, Chicago.

Dec. 9-12, AIChE, annual meeting, Statler Hotel, Boston.

Jan. 16, 1957, AIME, NOHC Western Local Section, Rodger Young Auditorium, Los Angeles.

Jan. 17-18, EJC, annual meeting, Statler Hotel, New York.

Jan. 22, AIME, Connecticut Local Section. Speaker: D. K. Compton, Chase Brass and Copper Co.; subject: *New Developments of Copper Alloys.* New Haven, Conn.

Feb. 24-28, AIME Annual Meeting, Roosevelt and Jung Hotels, New Orleans.

Mar. 10-13, AIChE, Greenbrier Hotel, White Sulphur Springs, W. Va.

Mar. 10-16, EJC Second Nuclear Engineering and Science Congress, Convention Hall, Philadelphia.

Mar. 13, AIME, NOHC Western Local Section, Rodger Young Auditorium, Los Angeles.

Mar. 13, AIME, NOHC Chicago Local Section, annual all-day meeting, Del Prado Hotel, Chicago.

Mar. 25-29, ASM And Others, Tenth Western Metal Exposition and Congress, Pan-Pacific Auditorium and Ambassador Hotel, Los Angeles.

Mar. 26, AIME, Connecticut Local Section. Speaker: P. C. Rossin, Universal-Cyclops Steel Corp.; subject: *Metallurgical Aspects of Vacuum.* Waterbury, Conn.

April 5, 6, AIME, Pacific Southwest Mineral Industry Conference. Sponsor: Nevada Local Section; cosponsors: San Francisco and Southern California Local Sections. Reno.

Apr. 8-10, AIME National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conferences, Penn-Sheraton Hotel, Pittsburgh.

Apr. 11-13, AIME, Pacific Northwest Regional Conference, Multnomah Hotel, Portland, Ore.

Apr. 16-17, AIME Regional Conference on High Temperature Alloys, Hotel Carter, Cleveland.

May 5-9, American Ceramic Soc., annual meeting, Statler Hotel, Dallas.

May 6, AIME, NOHC Chicago Local Section, spring meeting, Phil Smidt's Restaurant, Chicago.

May 12-16, Electrochemical Soc., Statler Hotel, Washington, D. C.

May 28-29, AIME, Reactive Metals Conference. Mining Branch sessions on May 28; Metals Branch sessions on May 28, 29. Ambassador Hotel, Los Angeles.

June 23-28, ASTM, annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.

Oct. 9-11, Joint Solid Fuels Conference, ASME-AIME Coal Div., Chateau Frontenac, Quebec.

Nov. 4-6, AIME, IMD Fall Meeting, Morrison Hotel, Chicago.

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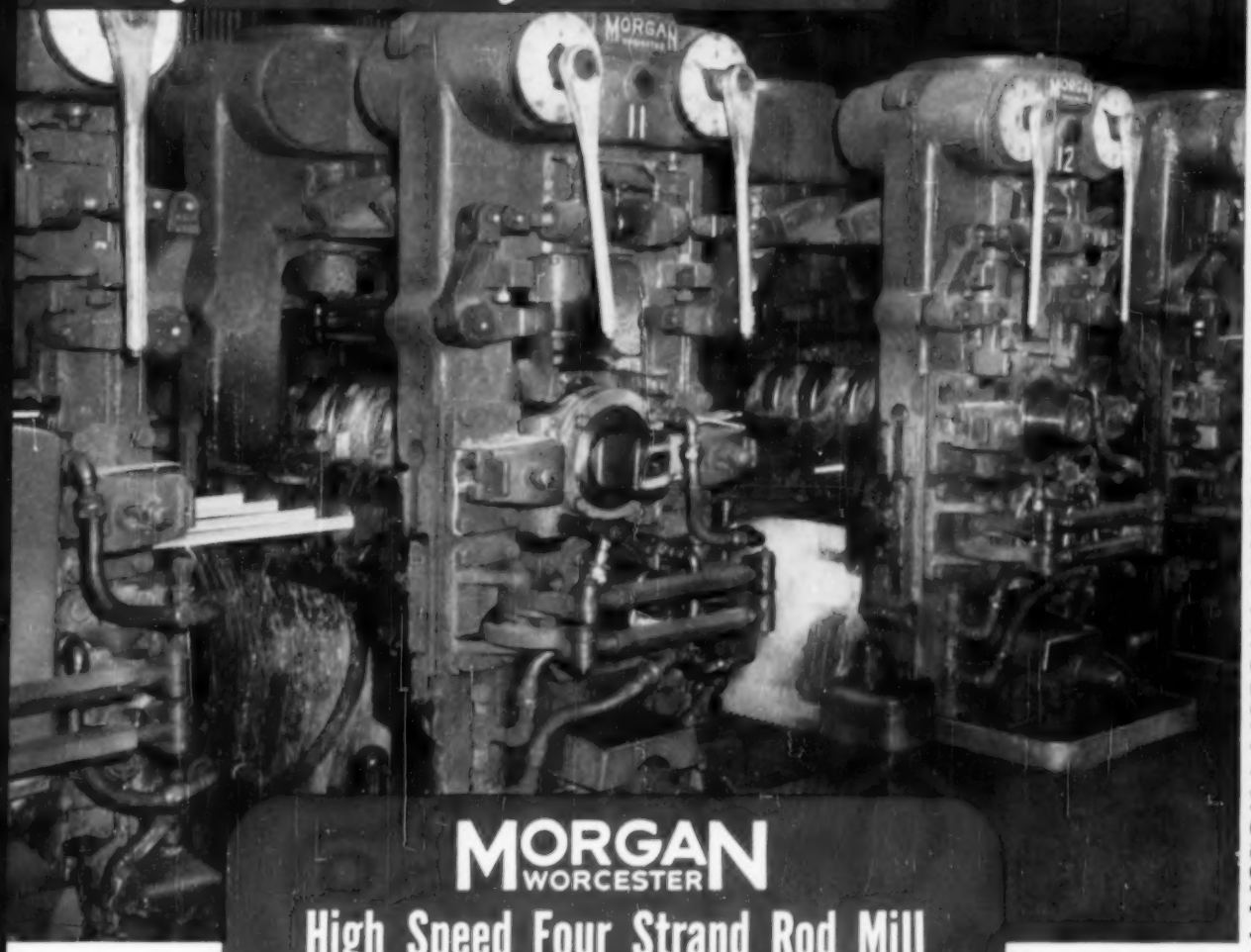

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DATA ON VOLMEX 81 . . .

HOW VOLMEX® 81

performs as a high volatile ingot mold coating when applied . . .

(1) Wet (2) Dry (3) At varying ingot mold temperatures

VOLMEX 81 is a highly volatile ingot mold coating which has been tested and adopted by a number of steel plants. The charts below are based on actual data obtained during such trial runs. Because of the differing practices employed by various companies, we have included several variables. First, because VOLMEX 81 can be applied either dry or with water as the carrier (spraying, swabbing or dipping are all practical), we have presented test figures on its use, both wet and dry. Second, we have included data on a range of ingot mold temperatures from 100°F. to 700°F., and third, we offer for comparison the results of a one-hour and a three-hour time-at-mold temperatures. No matter what method of application was used, VOLMEX 81 was found to repel metal splashes effectively before they could solidify and cling to the mold wall. At the same time, enough of the graphite-base coating was left at the metal/mold interface to keep the main body of the pour from clinging when it reached the point of splash, thus reducing surface defects. For wet application, VOLMEX 81 is easily stirred into suspension and remains in that state for hours without re-agitation.

VOLMEX 81 is the most volatile of the United States Graphite Company ingot mold washes. Others, in order of their volatility are: 90-B (non-volatile), MEX (very little volatility), and VOLMEX (volatile, but less so than VOLMEX 81). Write us for more extensive details or our engineering staff is available for on-the-spot assistance. Mold spray and mixing equipment are ready for your use in tests you may want to arrange.

Table I — **Volatility of VOLMEX 81 Ingot Mold Wash**

Mold Coating Volatility Test—VOLMEX 81 Water Application 2.75 lbs. powder/gal. water—Period—1 Hour at	Temperature 300°F.	500°F.	700°F.
% loss after heating for 1 hour	74.3	73.9	75.4
% loss on ignition at 1900°F. after 1 hour at specified temperature	16.1	14.4	11.3
Total percent volatile matter	90.4	88.3	86.7

Table II

Mold Coating Volatility Test—VOLMEX 81 Dry Application—Period—1 Hour at	Temperature 100°F.	300°F.	500°F.	700°F.
% loss after heating for 1 hour	0.1	0.8	0.9	2.8
% loss on ignition at 1900° F. after 1 hour at specified temperature	60.8	60.4	59.7	56.5
Total percent volatile matter	60.9	61.2	60.6	59.3

Table III

Mold Coating Volatility Test—VOLMEX 81 Dry Application—Period—3 Hours at	Temperature 100°F.	300°F.	500°F.	700°F.
% loss after heating for 3 hours	0.1	0.8	1.1	4.5
% loss on ignition at 1900°F. after 3 hours at specified temperature	60.6	59.6	59.7	53.1
Total percent volatile matter	60.7	60.4	60.8	57.6

You will note in the first chart which is the wet application, that the loss is all of the water contained plus a slight amount of the remaining volatile. Since on a weight basis, the powder is about ¼ of the make-up, if you will multiply the percent loss figures at 1900°F. by four, you will get an idea of the amount of volatile which would be present for loss during the pouring operation.

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